TABLE 3. Ground applications of insecticides for southern fire ant control on Nonpareil almonds, McFarland, California, 1981

Material	Formulated material per acre	Date applied	Visual ratings* Jul 8	Visual ratings* Aug 5	Nut damage†
					%
Lorsban 15G	20 lb	May 13	0.03	0.03	5.9
Lorsban 15G	20 lb	Jul 8		0.10	5.5
Diazinon 14G	20 lb	May 13	0.08	0.08	6.8
Diazinon 14G	20 lb	Jul 8		0.13	7.1
Lorsban 4EC	3 qt	May 13	0.23	0.30	11.6
Lorsban 4EC	3 qt	Jul 8		0.23	7.3
Diazinon 40W	3.5 lb	May 13	0.25	0.18	13.7
Diazinon 40W	3.5 lb	Jul 8		0.20	11.3
Diazinon 40W + Coax	3.5 lb + 2 lb	May 13	0.18	0.20	11.8
untreated check	. . .	. . .	0.08	0.74	14.3
LSD 0.05			0.21	0.24	4.1

*Visual ant colony ratings represent an average of four replicates. Ratings are on a scale of 0 to 1: 0 = no activity; 0.5 = weak colony; 1.0 = strong colony.
†Nuts were shaken on Aug 8, 1981 and remained on the ground for 11 days before damage was rated.

Ant hills in almond orchards often appear to be little more than patches of loose soil.

from each plot, hand-cracked, and rated for ant damage.

Lorsban 15G, Lorsban 4EC spray, and Diazinon 14G gave good control of the southern fire ant. Although some of the evaluations showed some reduction of ant activity by Sevin 20G, the effect was not present in the trial when evaluated on April 22, 1981.

Chemical trials were continued in 1981 with Lorsban and Diazinon granules and sprays applied on May 13 and July 8, Diazinon spray plus Coax applied on May 13, and an untreated check. These 1981 trials were conducted as in 1980, except that plots were eight trees long by two trees wide. Five strong colonies per treatment were tagged and observed throughout the season. A random sample of 50 nuts was harvested and rated for nut damage from each tree beside marked colonies.

Visual ratings indicated all materials gave good reduction of ant populations in marked colonies (table 3). Granular applications showed better control than the spray treatments, although the difference was not statistically significant. Nut damage was also higher in the sprayed plots than in the granular treatments.

Diazinon 14G was recently registered (California special local needs registration 24C) for ant control in bearing almonds. None of the other materials are currently registered for ants in almond orchards.

The granular materials applied in these trials appeared to eliminate the entire colony, including the queen. The spray formulations gave temporary control, possibly by reducing the worker force, but not affecting the queen. Therefore, the colony rebounded and caused damage later in the season.

The granular materials should be applied as needed. It is possible that annual applications will not be required. Application to the ground, especially as granular formulations, will minimize effects on nontarget beneficial insects and mites in the orchard.

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In the tropics, polycultures have long been an important component of small-farm agriculture. Farmers with limited resources traditionally intercrop their land to minimize risks and provide a stable source of income and nutrition, while maximizing economic and energy returns using primarily local technology.

Among potential advantages of intercropping systems are weed suppression through shading or natural plant toxins (allelopathy), reduction of insect damage by improving the balance of insect pests and associated natural enemies, better use of available soil nutrients, water conservation, erosion control, and greater productivity per unit of land. The study of such traditional systems has provided information useful as a basis for experimentation on sustainable cropping systems and less resource-intensive management technologies for developed countries.

Monocultural systems predominate in California commercial farms, but some farmers use polycultural arrangements, for example, by interplanting beans, snow peas, and other legumes among established apple, walnut, or almond trees. Some use fava or bell beans as cover crops in apple orchards or produce crops in various mixes, such as pears and grapes, corn and squash, cotton and alfalfa. Many farmers grow vegetables in small gardens for home consumption or sale in roadside stands. In these gardens crops such as tomatoes, hot and sweet peppers, cucumbers, dill, garlic, shallots, onions, cauliflower, cabbage, carrots, beans, squash, flowers, and herbs are intermingled on soil managed through mostly organic techniques.

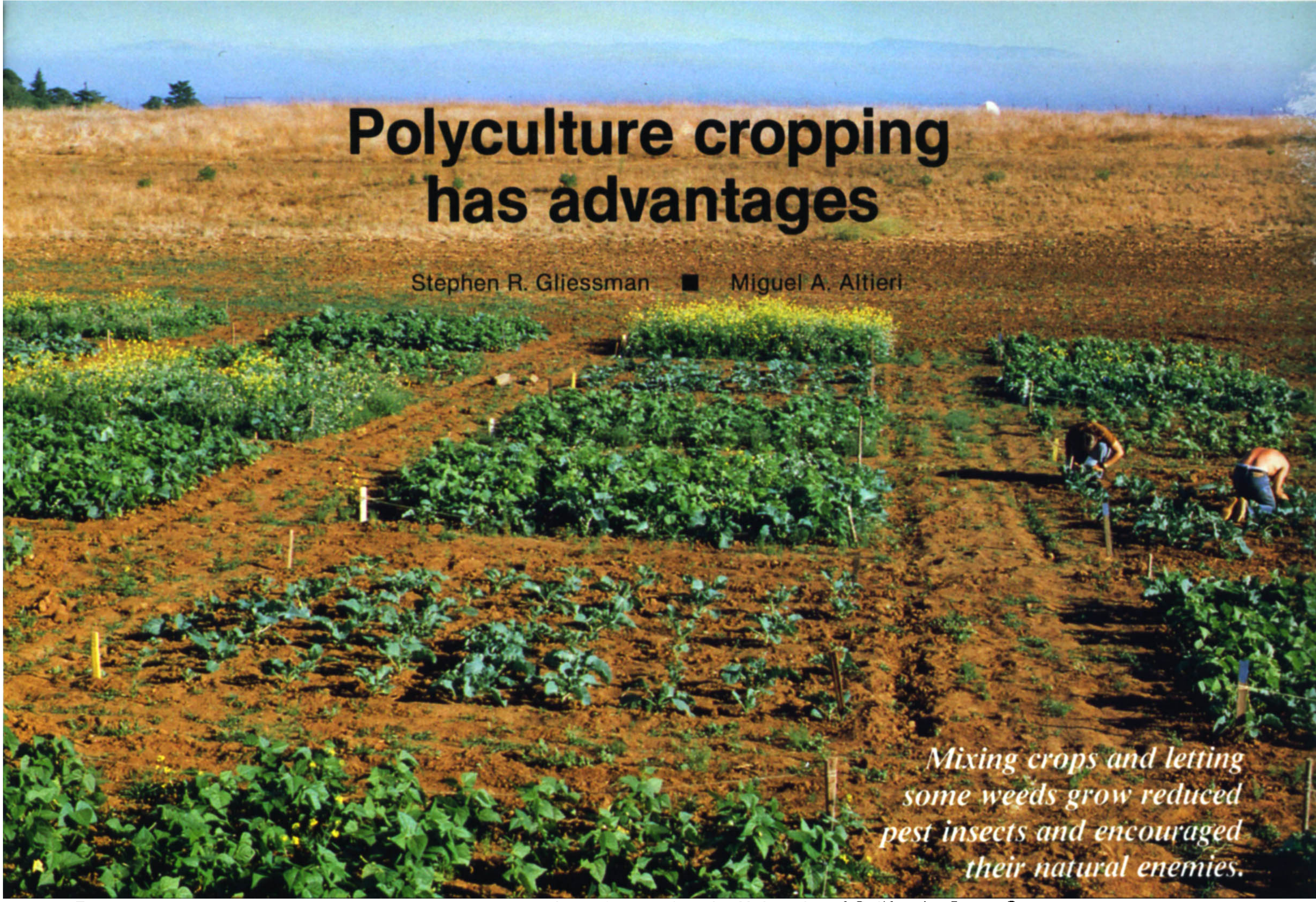
Such cropping systems have been adopted mainly by trial and error; very little formal research has been conducted to determine whether the combinations are profitable for the farmer with regard to pest and weed control, soil fertility, and productivity, and whether such methods may have smaller or much larger application.

California experiments

During the 1981 growing season, we conducted experiments at three California locations to compare polycultures of collards and green beans (Santa Cruz), brussels sprouts and fava beans (Albany), and corn and cowpeas (Davis) with corresponding monocultures in terms of incidence of pest insects, performance of natural control agents, weed competition, and yield potential. (In these experiments, "polyculture" refers to the simultaneous planting of two crops in the same area at the same densities of each as they would be planted separately in monocultures.) All treatments were replicated three times, and at each site monoculture and polyculture

Polyculture cropping has advantages

Stephen R. Gliessman ■ Miguel A. Altieri



Experimental collard-bean plots with varying degrees of weed control at the University of California, Santa Cruz.

plots received the same fertilization and irrigation regimes.

The flea beetle, *Phyllotreta cruciferae*, can consume large amounts of collard leaves. Interplanting beans or allowing weeds to grow with collards can considerably decrease flea beetle densities on the collards and minimize leaf damage (table 1). Cruciferous weeds in collard mono- and polycultures diverted flea beetles from collards, and insect feeding was concentrated on the weeds instead of on the crop.

Experiments showed that densities of the cabbage aphid, *Brevicoryne brassicae*, also were lower in collard polycultures (12 aphids per four plants) than in monocultures (43 aphids per four plants), apparently because of higher aphid parasitization rates by the important wasp parasitoid, *Diaeretiella rapae*. Again, aphid densities were lower in weedy than in weed-free mono- or polycultures.

Similarly, intercropping brussels sprouts with fava beans, and especially with a wild mustard, *Brassica kaber*, significantly reduced densities of the cabbage aphid on brussels sprouts. *B. kaber* plants seemed to provide favorable resources, such as flowers, pollen, nectar, and refuges, attracting a number of parasites (particularly *D. rapae*), which parasitized the aphids (table 2). The

TABLE 1. Flea beetles (*Phyllotreta cruciferae*) in various collard cropping systems in Santa Cruz, California

Cropping system	No. of flea beetles: Per 10 collards*	No. of flea beetles: Per 5 weeds†	Damaged leaves per collard‡
Collard monoculture			%
Weed-free all season	34.0 a	—	54.4 a
Weedy all season	6.6 b	25.0	29.9 b
Collard-bean polyculture			
Weed-free all season	2.3 c	—	34.1 b
Weedy all season	0.6 c	15.0	32.1 b

*Means followed by the same letter in each column are not significantly different (P = 0.05). (All means are averages of three sampling dates.)
†*Brassica* spp. weeds.
‡Percent leaves in each collard plant with insect damage.

TABLE 2. Cabbage aphid (*Brevicoryne brassicae*) populations and parasitization in mono- and polyculture brussels sprouts, 24-square-meter plots, Albany, California

Cropping system	Number of aphids*†	Parasitization*‡
		%
Monoculture		
Conventional density	147.7 c	4.4 a
Double density	44.0 a	13.3 b
Polyculture		
Brussels sprouts-fava beans	114.2 b	5.9 a
Brussels sprouts-*Brassica kaber*	61.9 a	15.5 b

*Means followed by same letter in each column are not significantly different (P = 0.05).
†Number of adult and immature aphids per five plants.
‡Percent parasitization of aphids by *Diaeretiella rapae*.

same effect was observed when the number of brussels sprout plants per plot was doubled.

Intensive cropping patterns appear to provide increased control of weeds. At Davis, weed cover and biomass production (dry weight) were lower in corn-cowpea polycultures (193 grams per square meter) than in corn (418 grams per square meter) or cowpea (1,529 grams per square meter) monocultures left weedy all season. At Santa Cruz, the bean-collard mixture suppressed both the number of plants and total biomass of the weeds, especially as compared with the slower growing collards planted alone (table 3). It is interesting that the overall reduction in weed growth in the polyculture appears to have allowed more species of weeds to occur. Maintaining all systems (at Davis and Santa Cruz) weed-free mechanically for two to four weeks after crop emergence also resulted in greater weed reduction.

Crop yields

The positive effects of polyculture cropping on yields can be seen in the data from Santa Cruz (table 4). The greatest number of harvestable collard leaves per square meter was obtained from the weed-free polyculture, although a slightly higher total dry weight, including stems and roots, was obtained in the monoculture kept weed-free for four weeks following seedling transplant.

Beans produced more pods and biomass in the monoculture plantings in all treatments except in the polyculture kept weeded four weeks following emergence. When polyculture bean and collard yields are combined, they far surpass those from the equivalent area planted separately to monoculture crops (see land equivalency ratio, table 4).

Conclusions

Many of the advantages of polycultures reported by researchers in the tropics now seem to be corroborated by these California experiments. Interplanting of nonhost crop plants or allowing limited weed population levels in polycultures significantly reduced numbers of plant-feeding insects *P. cruciferae* and *B. brassicae*. Possibly interplanting crops interferes with the pattern of perception of the crop by invading pest insects, thus making the crop less apparent to them. A more vegetationally diverse field would also seem to encourage the presence and activity of natural enemies and present complex microclimatic patterns unfavorable for the pest species.

Weed suppression can be a result of use of the available resources by crops. Combining crops of complex canopies can effectively shade out sensitive weed species. Such has been the case of the "milpas" of corn, beans, and squash used by traditional farmers in Mexico; these combinations exhibit highly competitive characteristics against weeds. Growing crops with different chemical byproducts may also enhance the possibilities for biological weed suppression through the release of chemical inhibitors.

In these experiments, although yields of a particular crop may have been lower in some polycultural situations than in monocultures, consideration of both crops in combination usually showed better use of the land and higher yields in polycultures.

Before polycultures can be more widely used in California, much more research is needed to determine optimum crop combinations, management techniques in relation to planting densities, time of planting, varieties, weeding regimes, and various agronomic practices. Also, mechanisms of pest and weed regulation need to be defined more precisely. Research on polycultures requires a multidisciplinary approach, including the development of machinery suitable for the new cropping systems.

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TABLE 3. Weeds in collard and bean test plots, Santa Cruz, California

Cropping system*	Weed population: Number of plants	Number of species	Dry weight
			grams
Beans			
Weed-free	0	0	0
4 weeks weed-free	78	10.0	64.1
2 weeks weed-free	127	12.3	205.5
Weedy	90	11.3	302.1
Collards			
Weed-free	0	0	0
4 weeks weed-free	42	8.7	52.3
2 weeks weed-free	52	9.0	55.2
Weedy	142	11.3	438.2
Beans-collards			
Weed-free	0	0	0
4 weeks weed-free	28	10.0	25.7
2 weeks weed-free	84	13.0	93.2
Weedy	85	14.0	234.5

*Weeding treatments, in 5- by 5-meter plots, were established by selective hoeing. Plots were weed-free or weedy all season, or were kept weed-free for 4 or 2 weeks after crop emergence, then allowed to become weedy.

TABLE 4. Yields from collard-bean experiment, Santa Cruz, California

Cropping system	Crop dry weight	Harvest yield	LER*
	g/m²	*units/m²*	
Monoculture beans		(pods)	
Weed-free	187.1	142.7	...
4 weeks weed-free	168.9	126.4	...
2 weeks weed-free	189.4	173.8	...
No weeding	162.7	113.1	...
Monoculture collards		(leaves)	
Weed-free	213.6	53.3	...
4 weeks weed-free	361.3	64.0	...
2 weeks weed-free	243.0	52.8	...
No weeding	226.1	50.4	...
Polyculture beans		(pods)	
Weed-free	174.5	113.8	2.07
4 weeks weed-free	239.5	131.5	2.01
2 weeks weed-free	104.3	76.1	1.50
No weeding	145.6	86.4	1.55
Polyculture collards		(leaves)	
Weed-free	334.4	68.0	2.07
4 weeks weed-free	324.0	62.0	2.01
2 weeks weed-free	309.4	56.2	1.50
No weeding	115.2	39.6	1.55

*LER (land equivalency ratio) = $\frac{Px}{Kx} + \frac{Py}{Ky}$, where Kx and Ky are the yields per unit area when crops are grown in monoculture and Px and Py are the yields of the two crops grown in polyculture. When this ratio is higher than 1, the polyculture yields are higher.