Winter 1991 - Vol. 2, No. 2

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Spring 1991 (v2n2)

Agronomy's role in sustainable agriculture: integrated farming systems.

Hildebrand, P.E.

J. Prod. Agric. 3: 285-288. 1990

Editor's Note: This analysis by Peter Hildebrand addresses the obstacles of practical research in sustainable agriculture in the U.S. A related article by MacRae et. Al., **[Agricultural science and sustainable agriculture: A review of the existing scientific barriers to sustainable food production and potential solutions (1989)]** *was summarized in Components Vol. 1 No. 3 It was an in-depth analysis of Canadian research institutions, but also described several strategies which could help improve U.S. research institutions.*

This article spells out the role that researchers and institutions must take on if sustainable agriculture is to be adopted on a large scale. For decades, farmers have applied broadly adaptable technologies to farms and field which vary greatly from one another. These technologies, including irrigation, chemicals, and mechanization, have been used to control the environment for maximum production. The result has been a high level of production and profitability, but at a cost to environmental and social well-being. "In the future," says Hildebrand, "new technologies will have to *conform* with the environments where they will be used, not *dominate* them. This means there will be an increasing need for location-specific solutions to emerging farm problems."

The author notes that the land grant system leaned toward specialization as technologies became more sophisticated. Increasing specialization led to problems in communication (and therefore collaboration) both within the research community, and between researchers and farmers. These problems are manifested in the emphasis on journal articles and on research which is designed to have a high probability of statistically significant, and at times obscure, results. "Practical significance takes a back seat, as does research directly applicable to solving farmers' problems." The dilemma is how to solve today's farm-specific problems with institutions that have seemingly inappropriate procedures and priorities.

The author suggests a change in methods, habits, and incentives in order to encourage a more sustainable form of agriculture. Many agronomists will need to become more familiar with the farm in order to base research on the needs of the farm. Thus, research will need to shift away from experiment stations toward on-farm experimentation in order to gain greater understanding of real farm environments and variability. In this scheme, farmers help to evaluate the results, rather than just observe results in a demonstration. An important advantage to this approach is that it can help researchers avoid selecting or rejecting technologies on the basis of their performance in an environment that may not be representative of the actual conditions in which the technology will be applied.

There should also be increased emphasis on multidisciplinary research, rather than strictly component research. The author does not simply suggest that research should be done by committees, in which individuals from various disciplines meet periodically to coordinate their efforts. Rather, "agronomists should work with anthropologists and economists to assure that these social scientists have an adequate understanding of the crop components of the farming systems. They, in turn, will help assure that agronomists understand the human elements and their impact on the crop systems." To help accommodate this shift in research organization, modifications of administrative structures and professional evaluation procedures are also suggested.

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(CI-SUST.038) *Contributed by Chuck Ingels*

Crop production during conversion from conventional to low- input methods.

Liebhardt W.C., R.W. Andrews, MN. Culik, R.R. Harwood, R.R. Janke, J.K. Radke and S.L. Rieger-Schwartz

Agronomy J. 81:150-159. 1989

This cropping systems experiment was initiated in 1981 to help answer questions about the transition from a conventional production system (short rotation, pesticides, fertilizers) to a low-input system. In this study, "low-input" refers to production systems that utilize internal resources generated on the farm. Pest control, for example, is accomplished using cultural and biological techniques; nutrients are supplied through incorporation of animal and green manures.

A USDA organic farming study (1980) stated that many mainstream farmers experience significant yield reductions the first three to four years after switching to organic methods. Similar findings have been reported in other comparative studies, but little research has been done to explain the reasons for this yield reduction. Researchers on this experiment were interested in addressing this dilemma. Specifically, their objectives were to: 1) Define the yield-limiting factors that occur during the transition process; 2) Identify methods of minimizing yield reductions; and 3) Identify physical, chemical, and biological processes that occur during the conversion to low-input methods.

Materials and Methods

A 6.1 ha field experiment was established on a farm adjacent to the Rodale Research Center in east--central Pennsylvania. The site had a three percent south-facing slope and a silt loam soil. Three farming systems, each consisting of a five year rotation, were compared: 1) Low-input/ Livestock (LI-L); 2) Low-input/Cash Grain (LI-CG); and, 3) Conventional (CONV). Within each cropping system the effect of the rotation on the conversion process was taken into account by initiating the rotation at three different entry points in the sequence (Table 1). Researchers used a split-plot randomized block design with eight replications. Cropping system was the main plot and the crop rotation entry points were subplots. Main plots were 18.3 x 91.5 meters. Grass buffer strips 1.5 meters wide were established between main plots to minimize movements of nutrients and pesticides between treatments. Prior to 1981, the experimental site was farmed conventionally in a corn-wheat rotation, winter wheat being harvested in the summer of 1980. Each year, researchers measured: 1) grain and hay yields; 2) corn dry matter production; 3) leaf tissue nutrient concentrations of corn, soybean, small grains; 4) green manure biomass and nutrient content; 5) animal manure nutrient content and quantity applied; and, 6) weed biomass in both corn and soybean.

Results

Table 2 summarizes data for a few of the measured parameters. The authors highlight several key points from these data noting the following:

- Corn grain yields were consistently lower in the low-input plots compared to conventional during the first three years (about 60 percent of conventional). In the fourth year of the experiment, 1984, this yield gap began to narrow and in year five no yield differences were detected between low-input and conventional systems. This was attributed, in part, to planting hairy vetch as a cover crop rather than red clover in 1984. The nitrogen contributed by the vetch (180 kg N per ha at plow down) was much greater than that contributed by the clover in previous years.

- Nitrogen concentration in corn leaf tissue varied with the source of nutrient. Fertilizer applied to conventional plots in 1981 improved the nitrogen concentration over unamended low-input plots. But after one season of a red clover cover crop, no difference in N concentration between the two systems was found. (The *yield* difference between the two systems in 1982 was attributed to weed problems and the use of a shorter season variety in low-input plots.) Even though similar amounts of manure were incorporated into the two LI-L treatments in 1983, preceding crops of red clover hay resulted in higher leaf nitrogen concentration than did a corn-soybean sequence. Differences in nitrogen uptake between the three cropping systems were not explained.

- Foxtail (*Setaria* sp.) was the dominant weed in corn during the first four years of the experiment. Rotary hoeing and cultivation in low-input plots were not as effective in controlling weeds as the herbicides used in conventional plots. Weed biomass in low-input plots was generally kept below 1 Mg per ha except in 1982 when a wet spring resulted in poor timing of tillage operations. In 1985, a significant weed species shift was observed in the LI-CG system. Instead of foxtail, the predominant weeds were broadleaf species including lambsquarters, velvetleaf, and pigweed. Overall weed biomass in the LI-CG system was much lower in 1985 than in previous years and not significantly different from the conventional system.

- Soybean yields in the three cropping systems were not significantly different except in 1982 and 1985 when yields in the low-input plots (notably LI-CG) were greater than in conventional plots.

Conclusions

From this study, the researchers concluded that corn was not the best choice for a transition crop. This is for two reasons. First, it has a high nitrogen demand that may be difficult to meet initially with animal or green manures. Second, where corn growth is suboptimum, it is not able to compete well with weeds. Conversely, "weed control in the low input systems was improved where Nuptake by the crop was adequate, the corn stand was well-distributed, and growth good." The authors also concluded that a change in the crop sequence may be necessary where nitrogen and weeds are limiting factors. In this case, rotations that included soybean, small grain, and/or legume hay during the first three or four years may have been more successful.

Three principles to follow when converting to a low-input system are suggested:

1. Begin with crops that have a low nitrogen requirement or which fix their own N. Initial crops should also be able to compete against the weeds present in the field.

2. Shift between warm- and cool-season crops in the rotation. This disrupts the life cycles of various weeds and reduces competition in alternating crops. In the low-input/cash grain system, for example, foxtail (a warm-season weed) could not compete well with the well-established cool-season wheat crop

3. The transition can be facilitated by gradually reducing fertilizer and pesticide inputs. Herbicides could be banded and used in conjunction with cultivation; nitrogen fertilizers could be used to supplement nutrients added from animal or green manures.

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U.S. Department of Agriculture. 1980. Report and Recommendations on Organic Farming. U.S. Government Printing Office. Washington, D.C.

Table 1.

Crop Sequences for Low-Input and Conventional Farming Systems						
		----Rotation----				
Farm System	**Entry Pt.**	**1981**	**1982**	**1983**	**1984**	**1985**
Low-Input/ Livestock	1	oat + clover	clover	corn	soyb	corn (feed)
	2	corn	soyb	corn (feed)	wheat clover	clover (yr 2)
	3	corn (feed)	wheat clover	clover (yr 2)	corn	soyb
Low-Input/ Cash Grain	1	oat + clover	corn	oat + clover	corn	soyb
	2	soyb	oat + clover	corn	wheat vetch	corn
	3	corn	soyb	oat + clover	corn	oat + clover
Conven.	1	corn	corn	soyb	corn	soyb
	2	soyb	corn	corn	soyb	corn
	3	corn	soyb	corn	corn	soyb

Table 2.

Comparison of Low-Input and Conventional

Cropping Systems for Selected Parameters						
Parameter/ System	**Previous Crop**	**1981**	**1982**	**1983**	**1984**	**1985**
Corn Grain Yield		-- Mg/ha --				
Ll-L	legume	1.56b	--	5.52ab	8.70b	--
Ll-CG	legume	1.37b	5.47b	4.60b	7.41c	9.57a
CONV	corn	2.37a	9.56a	5.92a	9.33ab	--
	soyb.	2.54a	8.59a	6.35a	9.96a	8.54a
Corn Tissue [N]		-- g/kg --				
Ll-L	legume	19.8c	--	27.3a	25.8b	--
	soyb.	24.1b	--	19.0d	--	25.0c
Ll-CG	legume	20.3c	26.0a	24.9b	26.1b	31.7a
CONV	corn	28.7a	27.4a	22.0c	29.8a	--
	soyb.	29.5a	26.6a	23.9b	29.9a	29.2b
Weed Biomass (Corn)		-- Mg/ha --				
Ll-L	legume	0.95a	--	0.44c	0.89a	--
	soyb.	0.89a	--	0.63b	--	2.12a
Ll-CG	legume	0.83a	2.51a	0.91a	1.00a	0.27b
CONV	corn	0.38b	0.09b	0.07d	0.24b	--
Soybean Seed Yield		-- Mg/ha --				
Ll-L	corn	--	3.29a	--	3.56a	3.42ab
Ll-CG	corn	1.78a	3.31a	--	--	3.58a
CONV	corn	1.78a	2.87b	2.83	3.53a	3.31b

1 Crop preceding 1981 was wheat in all cases
2 Parameter values for each year followed by the same letter are not significantly different, $P < 0.5$, as determined by Duncan's multiple range test. No data-indicates that the crop was not in the rotation for that system.

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(DEC.272) *Contributed by Dave Chaney*

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Spring 1991 (v2n2)

Low-Input farming In practice: Putting a system together and making it work.

Kirschenmann, Frederick

American J. Alternative Agriculture 4(3,4): 106-11O. 1989

In this article North Dakota organic farmer Fred Kirschenmann offers his suggestions for growers who are interested in moving toward more sustainable, resource-conserving production systems. At the out-set, it is important to consider where you are headed, what the goal is for your farm. Kirschenmann is in favor of making sustainability the goal rather than reducing inputs. To him, low-input suggests "getting by with less" rather than "restoring what we use to keep going". The former may improve short-term efficiency, but the latter is crucial for solving some of the long-term problems facing agriculture. Kirschenmann opts for the broad definitions of sustainable agriculture suggested by Wendell Berry, William Lockeretz, and Stuart Hill:

- an agriculture that depletes neither soil nor people (Berry)
- agriculture that is capable of enduring (Lockeretz)
- a system based on renewable resources, the recycling of non-renewable resources, and minimum environmental impact (Hill)

There are numerous approaches and many starting points for attaining a sustainable farming system, but Kirschenmann recommends a "whole systems approach." This involves experimentally introducing a complete sustainable system on a small portion of the farm. Based on the results and observations that come from this small piece, a farmer could then begin to apply the process to the rest of the farm. From years of experience, Kirschenmann has noted several concepts and themes that growers should think about as they make the transition. These fall into four categories: pitfalls to avoid, practices to incorporate, problems to anticipate, and principles for success.

Pitfalls to Avoid

Kirschenmann discusses three errors that can lead to disastrous results: 1) Believing that "successful farm-ing is a matter of following the right recipe"; 2) Trying to transfer a potentially sustainable system to the whole farm at once; and 3) Changing farming practices or substituting inputs without modifying the whole system.

Practices to Incorporate

Apart from orchards and vineyards, establishing an appropriate crop rotation scheme is one of the best ways to manage pests and improve or maintain soil quality. This can be a difficult task so Kirschenmann offers these guidelines: 1) The rotation should control weeds; 2) The rotation should control insects and diseases; and 3) The rotation should improve and maintain good soil conditions. Some specific strategies for controlling weeds include:

- Alternate cold and hot weather plants.
- Include allelopathic plants.
- Include crops/cover crops that can out-compete weeds.
- Include crops that lend themselves to mechanical control.
- Adjust rotations for problem perennial weeds.
- Include a range of crops to improve nutrient status and soil physical condition. This can give a competitive advantage to the growing crop.

To improve soil conditions, Kirschenmann urges growers to include both deep-rooted and fibrous-rooted crops to increase aggregation and water holding capacity. For insect and disease control, farmers should try to isolate crops, in both space and time, that are susceptible to the same pests.

Another important management principle is to develop a regenerative soil conserving strategy. Rotations are also important here, especially from the standpoint of using cover crops and green manures that can fix nitrogen and promote the cycling of nitrogen and other nutrients through the production system. Improvements in fertility and tilth can also significantly reduce the erosion potential. The use of livestock manures and composts can supply similar benefits to the soil.

Finally, Kirschenmann emphasizes the importance of increasing farm diversity and capitalizing on the interaction between various components of the system. The best example of this is the inclusion of both crops and livestock in the farming system. Crop residues and hay or pasture in the rotation can supply feed for live-stock. In turn, animal manure can be composted and returned to the field to maintain fertility. Improved diversity can also help farmers survive hardships imposed by economics or adverse weather.

Problems to Anticipate

Growers making this transition should be prepared to face a number of problems. The article highlights five:

1. Instability and "withdrawal" symptoms can result as the production system reaches a new equilibrium. This may require the continued use of pesticides and fertilizers during the transition period.

2. Additional facilities to store new crops and/or to house livestock may be needed.

3. New management practices require new or additional equipment and machinery.

4. It is likely that additional labor will be required.

5. Until effective control strategies can be implemented, weeds will probably

be a big problem.

Principles for Success

Although there is no standard recipe or formula for establishing a more sustainable farming system, Kirschenmann offers seven points to help increase the chances of success. Inspired by Niccolo Machiavelli, the 16th century Italian statesman, Kirschenmann urges growers to: 1) Recognize problems in a timely manner through close, personal observations; 2) Let the new system develop at its own pace in accordance with natural growth patterns; 3) Maintain some degree of impetuosity; 4) Accept the ambiguity and inconsistencies of the system; S) Keep a firm commitment to the goals of sustainable agriculture; 6) Use imagination, and maintain a sense of humor; and 7) Become part of a support group to gather and share information with other growers.

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(DEC.269) *Contributed by Dave Chaney*

Spring 1991 (v2n2)

Allelopathic interrelations for weed control on arable land.

Pawlowski, L. and G. Bachthaler

Angew. Botanik 1989

Reviewer's note: Allelopathy is generally defined as the suppression of the growth of one plant species by another due to the release of one or more chemical compounds. The toxic substance may be released by the living plan4 most likely through the roots, or it may be released from nonliving plant residues. This paper reviews, in German, historical and current information regarding allelopathic interrelationships of crop plants and weeds (92 references). The following summary is based on a translation of the article from German into English by Hans Rocke, UC Davis Librarian.

The term "allelopathy" was coined in 1937 by H. Molisch, who demonstrated that remarkable changes in one plant could be induced by gaseous substances released from other plants or plant parts. The authors agree with the usual concept of allelopathy (suppression of plant growth), but also include growth promotion effects. For example, several studies are cited in which substances released by weeds were reported to stimulate the growth of crop plants such as rye, wheat, cabbage, and turnips.

Three variations on using allelopathy in agriculture are addressed: growing plant species with allelopathic potential, using plant residues, and applying synthetic allelochemicals.

Growing plant species with allelopathic potential involves the production of crop plants which suppress the growth of weeds during their growing season. In one study, allelopathic growth inhibition was discovered in oat, poppy, wild mustard, rye, wheat, chamomile, and wild mustard. Other studies are cited in which crop species such as cucumber, corn, sorghum, and soybean exhibited allelopathic effects. Conventional plant breeding has been unsuccessful in developing crop varieties that produce more of a particular allelochemical, but genetic engineering may offer some potential in this area.

Using plant residues involves the use of plant residues to inhibit weed development the next season. It was noted that by the year 2000, nearly 20 percent of the acreage farmed in the U.S. will use conservation tillage. This means that more plant material will remain on the soil surface or in the top layer. Studies were cited in which the residue of rye, barley, oats, wheat, and sorghum had an inhibitory effect on various weeds. The review did not distinguish allelopathic inhibition from mulch effects.

Applying synthetic allelochemicals. One study showed a chemical correspondence between different allelopathic groups of substances and synthetic herbicides. If these substances could be isolated in some way they could be a first step in developing alternative herbicides. There is increasing

interest in using microorganisms for this purpose; actinomycetes look the most promising because they produce numerous antibiotics. The disadvantages of this approach are:
1) the intensive labor involved in identifying compounds; 2) the small yield of material that can be obtained; and 3) the lack of selectivity in the use of the material as an herbicide. Other research have shown that parasitic plants, particularly *Striga* species, are another potential source of allelochemicals.

Other highlights of this article include examples of the relationship of nutrient uptake with allelopathy, possible allelopathic crop-weed relations in corn fields in northwest Mexico, and a system of mixed cultivation for biological weed control among crops. Despite decades of research, only a few practical applications of allelopathy have been developed.

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(CI-PEST.028) *Contributed by Chuck Ingels*

Influence of irrigation management on the abundance of leafhoppers (Homoptera: Cicadellidae) on grapes.

Trichilo, P.J., L.T. Wilson, and D.W. Grimes

Environ. Entomol. 19(6): 1803-1809 1990

What is the optimum amount of water to apply to grapes in order to maximize production and minimize leafhopper populations? That is the question a group of researchers set out to address in a three-year irrigation management study. This subject is important for grape growers because of drought concerns and because production hinges on optimum vine vigor. Vine vigor has been reported to be so closely related to irrigation that some researchers suggest using shoot elongation as a criterion for timing irrigations.

The experiment was conducted in drip-irrigated vineyards at two University of California sites, Kearney Agricultural Center and Westside Field Station. At Kearney, five irrigation levels (0.4, 0.6, 0.8, 1.0, and 1.2 ETcrop) were used, and at Westside, three irrigation levels (0.4, 0.8, and 1.2 ETcrop) and two water cutoff dates were tested. Leafhoppers were sampled weekly at both sites.

While results were mixed, the number of leafhoppers per leaf increased as irrigation level increased. This finding suggests that leafhoppers favored vines with high water potential. One possible explanation was that water stress increased the concentration of allelochemicals and therefore reduced the digestibility of the plant. More likely, cooler canopy temperature, which was associated with higher irrigation rates, may have contributed to greater leafhopper densities. This conclusion is supported by the fact that more leafhoppers were found in the more shaded areas of the vine (north and east) than the sides which were more exposed to the sun.

Differences in leafhopper densities between irrigation rates were far more evident at the Westside site than at Kearney. The authors speculated that the clay loam soil at Westside held water more tightly than did the sandy loam soil at Kearney. The vines at Westside were presumably under greater stress and therefore had higher leafhopper densities.

Relative yield data for this experiment were presented in another study (Grimes and Williams, 1990). Each of three plant-based methods of assessing water stress showed decreased production with increasing stress. However, yields were greater and leafhopper densities were usually lower for 1.2 ET with early water cutoff than for 0.8 ET at the normal water cutoff date. This finding is important since a major brood peak usually occurs after an early cutoff date. The authors therefore propose an irrigation level of 1.0 ET with an intermediate cutoff, around late July, as a compromise between water use and pest effects.

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Grimes, D.W. and L.E. Williams. 1990. Irrigation effects on plant water relations and productivity of Thompson seedless grapevines. Crop Sci. 30:255-260.

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(CI-GRA.001) *Contributed by Chuck Ingels*

Spring 1991 (v2n2)

Ecological management of plant-parasitic nematodes.

Caswell, Edward P. and Robert L. Bugg

Article written for Components. 1991

Nematodes (Greek for "thread-like things") are un-segmented invertebrate animals that are worm-like in appearance. Nematodes are found in marine, fresh-water, and terrestrial habitats. There are approximately 15,000 recognized nematode species. They range in length from less than 0.3 mm (many of the plant-parasitic species) to over 8 m (a parasite of whales).

Soil-dwelling nematodes play important roles in soil ecology and participate in many biological processes affecting crop plants. Many are motile, propelling themselves through soil moisture films by a dorso--ventral undulating motion. Different species of nematodes may feed on fungi, protozoa, bacteria, tardigrades, enchytraeids, and probably other organisms as well (Freckman and Caswell, 1985). Some species feed on other nematodes and their eggs.

About 2,200 species of nematodes are known to attack plants (Maggenti, 1981). Most attack roots and below-ground tissues of plants, although some species infect plant foliage. The most economically important groups of plant-parasitic nematodes are the root-knot (*Meloidogyne* spp.), root-lesion (*Pratylenchus* spp.), cyst (*Heterodera* spp.), sting (*Belonolaimus* spp.), and reniform (*Rotylenchulus* spp.) nematodes. The taxonomy is based largely on visible differences in the morphology and anatomy. Nominal species, however, may contain races of differing host ranges and virulences. The life-cycle of a typical plant-parasitic nematode takes approximately 25 to 30 days at a temperature of 25C. Root-knot and cyst nematode females produce from 250 to 500 eggs during that time.

Crops grown on sandy soils are typically prone to nematode problems because of environmental conditions which favor nematode development and reproduction. These include larger pore sizes (allowing for nematode movement), and better drainage and aeration. An additional factor may be that heavier clay soils typically retain organic matter longer than do sandy soils. As will be seen later, organic matter and associated organisms may be important in suppressing plant-parasitic nematodes.

Control VS. Management

Plant-parasitic nematodes can be a major limiting factor in crop production. Control and management are two important concepts for dealing with nematode problems. *Nematode control* refers to specific tactics applied to reduce or eliminate nematode populations, while *management* describes efforts to reduce nematode numbers to non-damaging levels through the application of several control procedures in combination or in sequence (Thomason and

Caswell, 1987).

Nematode control in United States agriculture has been heavily dependent on the use of nematicides. However, environmental and health problems associated with many of these pesticides have prompted an interest in developing cropping Systems that reduce pest populations. A dramatic stimulus to research on alternative nematode management strategies was added in 1990 when the California Department of Food and Agriculture (CDFA) canceled all Restricted Material Permits for the application of 1,3-D, one of the few remaining fumigant nematicides available in California. Some alternative management strategies are available, and others are being researched. However, it is unlikely that a new "magic bullet" nematode control method will cure all remaining nematode problems. Future nematode management will probably utilize several different control tactics in combination.

Nematode Management Options

Damage Thresholds and Planting Dates. Nematode management decisions require knowledge of the nematode population densities in a field. Because of variations in soil type, cropping history, slope, and other factors, nematodes do not occur uniformly across a field. Accurate determination of nematode populations requires collection of representative soil samples. To collect a representative soil sample: 1) Divide the field into blocks that are as uniform as possible with respect to cropping history and soil type; 2) Collect soil samples when the soil is relatively moist; 3) Sample each block within the field so that a minimum of 15 to 20 soil cores are collected per sample (cores should be at least 12 inches deep and an individual sample should represent no more than five acres); and 4) Enclose the samples in a plastic bag and mail them immediately to a processing lab together with information on the location, soil type, crop history, symptoms, proposed crop, and the time and type of last nematicide treatment (Ferris et al., 1981).

The relationship between nematode numbers and crop growth and yield is complex, and varies with the nematode species and the crop species or variety. Usually, the more plant-parasitic nematodes there are in the soil the lower the expected yield from the crop. The damage threshold is the nematode population density below which no damage is expected, while above the damage threshold crop yields are expected to be reduced. Damage thresholds are now available for many different crops (Ferris, 1986), and these are valuable for making decisions on management options.

An additional consideration regarding potential damage by nematode populations concerns planting dates, soil temperatures and nematode activity. Nematode activity is temperature dependent. When soil temperatures are too cool, nematodes are not active. Many crop plant species are able to grow at temperatures that are too cool for the relevant nematodes to be active. For example, *Meloidogyne incognita* juveniles can migrate through soil and penetrate roots only at temperatures above 18C; however, after the juveniles penetrate roots they can complete development at lower temperatures. So, delaying planting of winter wheat until soil temperatures are below 18C, for example, will enhance the winter decline of *M. incognita* in soils (Roberts et al., 1981).

The influence of nematodes on plant growth is, in part, a function of the stage of development of the plant at the time of infection. Again, if planting dates are manipulated to assure that soil temperatures allow some plant growth prior to nematode infection, the damage to the plant is reduced. For example, *Heterodera schachtii* is much less pathogenic on sugar beet seedlings infected after six weeks of growth than if infection takes place in the germinating seed. In field experiments, *H. schachtii* was less pathogenic to sugar beets planted when soil temperatures were 6C than to sugar beets planted when soil temperatures were 24C (Griffin, 1981).

Plant Resistance. Host plant resistance to nematodes is an important alternative to nematicides. Plant resistance has been developed primarily for the specialized, sedentary endoparasites, the root-knot and cyst nematodes (*Globodera, Heterodera, Meloidogyne*). A few cultivars resistant to Ditylenchus have also been developed (Fassuliotis, 1987). Sources of resistance have been identified for many different crop plants. Cultivars with some level of resistance are available for many different crop plants, including alfalfa, beans, citrus, cotton, grape, oats, potato, soybean, sweet potato, tobacco, tomato, walnut, and stonefruits.

The implementation of resistance has been successful; however, resistance-breaking pathotypes have been identified for some cultivars. This has been a frequent problem with cyst nematodes, and has been observed in the root-knot nematodes as well. This phenomenon highlights the need to maintain diverse, destabilizing selection pressures on nematode populations in the field, to prevent the eventual domination of the population by particularly virulent strains.

Soil Amendments. Organic soil amendments have long been considered beneficial in managing plant-parasitic nematodes. Linford (1937) observed that adding organic matter to soil increased the activity of nematode-trapping fungi. The beneficial effect of organic matter incorporation is generally considered to be due to direct or indirect stimulation of predators and parasites of plant-parasitic nematodes. The incorporation of organic matter may serve to increase the nematode community diversity. This increased diversity can prevent the domination of the nematode community by a single species, encourage the activity of nematode antagonists, and increase linkages within the soil food web. Additional research is required in this area.

The addition of organic matter may provide an energy source for facultative nematode parasites, such as some fungi. Many of the successful experimental additions of nematode-parasitic fungi to soil have included the addition of organic matter to the soil along with the fungus. The enhancement of nematode-trapping fungi by organic matter often lasts for only short periods of time, a few weeks for example, and does not typically exert a strong effect on nematode population densities (Kerry, 1987).

Amending soil with chitin has in some cases been shown to reduce populations of *Meloidogyne javanica* and other species of plant-parasitic nematodes (Spiegel et al., 1986, 1987). Chitin amendments seem to suppress nematode populations through the release of nematicidal ammonia during decomposition, and by stimulation of chitinolytic organisms such as bacteria and actinomycetes that attack nematode egg shells (Culbreath et al., 1986; Spiegel et al., 1987, 1988). Because ammonia is released by chitin amendments, they can be phytotoxic when added to the soil at high concentrations. However, the addition of hemicellulosic waste together with the chitin may reduce the phytotoxicity (Culbreath et al., 1985). Typical chitin application rates for successful nematode control are three to four tons per acre (Rodriguez-Kabana, personal communication; Spiegel et al., 1986, 1987, 1988), making the cost of chitin application prohibitive for many crops.

Crop Rotation. Rotation to non-host crops is a valuable means for reducing damage by plant-parasitic nematodes. This approach can be particularly effective with nematodes that have a limited host range, such as the sugar beet cyst nematode (*H. schachtii*). However, it is less likely to be successful with nematodes that have a wide host range, such as the root-knot nematodes (*Meloidogyne* spp.) and the root-lesion nematodes (*Pratylenchus* spp.). There are at least two important points that must be considered when this approach is implemented: 1) When non-host rotation crops are used, weed control may be necessary to deny the nematode access to host weeds; and, 2) Most fields are infested with several different species of plant-parasitic nematodes, and a rotation crop may be a host for at least one of the species resulting in increased numbers of that nematode in the field.

Cover Crops

Cover crops grown to sustain soil fertility will influence other aspects of the cropping system including, nematode densities, weeds, pest insects, beneficial insects, and diseases. These side-effects may either inhibit or enhance the associated cash crops. Therefore, cover crops should be selected with the whole cropping system in mind. Cover cropping specifically for suppression of nematodes is receiving increased attention (Reddy et al., 1986; Yeates, 1987; Rodriguez-Kabana et al., 1988a). Cover crops can affect plant-parasitic nematodes by: 1) acting as non-hosts and preventing nematode reproduction; 2) producing root exudates that stimulate nematode activity in the absence of a host resulting in increased nematode mortality; 3) producing root exudates that are nematicidal; or, 4) producing compounds in the foliage that, when incorporated into soil, are nematicidal.

Selecting appropriate cover crops to reduce nematode numbers requires a knowledge of the nematode species present in a field, as a particular cover crop may be a host to one species of nematode and a non-host for another species. For example, McKenry et al. (1990) found that 'Cahaba White' vetch (*Vicia sativa x V. cordata*) is an excellent host for *Meloidogyne hapla* but a poor host for *M. javanica*. In addition, when grown in a companion planting with crops, some covers may exert a deleterious affect on crop yield and this should be considered. Other research on cover crops and nematodes has been conducted in the southeastern United States, where the warm climates and sandy soils result in severe nematode problems. For several moderate-value crops in this area, the cost of nematicides is prohibitive, so alternative cultural controls are desirable.

Cool-season cover crops grow during the fall, winter, and early spring. Some cover crops may be able to avoid nematode damage during this period because it is when plant parasitic nematodes are least active. However, cover crops differ in their susceptibility to nematodes and infection can still occur if conditions are right. For example, if cool-season cover crops are sown during

September in nematode-infested soils, persistent warm weather may allow the nematodes to parasitize the cover crop. Timing of seeding and tillage are also important in determining the degree of nematode activity, and the extent to which nematodes attack the cover crops.

Rodriguez-Kabana and Ivey (1986) explored the effects of crop rotations for managing *Meloidogyne arenaria* in peanut. They found that a winter cover crop of **cereal rye** (*Secale cereale*) had no effect on nematode densities in the following summer crops of peanut, soybean, or corn, but the cover crop did lead to yield increases in the soybean and corn.

McSorley and Dickson (1989) grew rye and **hairy vetch** (*Vicia villosa*) as cool-season cover crops in monocultural plots on a sandy soil in Florida, to determine effects on six species of nematodes over two years. In early April of each year, cover crops were mowed and disked and then planted to soybean (*Glycine max*). The experimental design did not permit comparison of rye to hairy vetch. In most instances cover cropping for three or five months resulted in maintenance of' or slight decline of' pre-existing nematode densities. Growth of rye resulted in increased densities of *Belonolaimus longicaudatus*.

In Florida, Gallaher et al. (1988) tested **hairy vetch** and four **vetch cultivars** ('Vantage', 'Cahaba White', 'Vanguard', and 'Nova II') in sandy loam soil, using tillage and no-till regimes preceding corn or sorghum. M. incognita densities were much higher on hairy vetch than on any of the four vetch cultivars. The root-gall index was highest for hairy vetch. *Criconemella ornata* were at relatively-high densities on 'Vantage', 'Cahaba White', and 'Vanguard'. *Pratylenchus brachyurus* and *P. minor* attained statistically-similar densities on all five vetches. Numbers of P. brachyurus per 10 g of roots were particularly high for 'Cahaba White', and 'Vanguard'. The tillage regime had little effect on nematode densities, except that ring nematode occurred at significantly higher densities under no-till management.

To date, **subterranean clovers** (*Trifolium subterraneum*) have shown limited resistance to *Meloidogyne* spp. (Baltensperger et al., 1985; Kouame et al., 1989; Pederson and Windham, 1989). This suggests potential problems for vegetable crops grown in rotation or as intercrops.

Sacka-Kuri et al. (1986) evaluated five cultivars ('Auburn Reseeding', 'Tibbee', 'Chief', 'Dixie', and 'Autauga') and three advanced lines of **crimson clover** for reaction to three *Meloidogyne* species. All were intermediately to highly susceptible.

In Mississippi, Windham and Pederson (1989) assessed the sensitivities of three **white clover** cultivars and two germplasms to four races of *M. incognita*. All the white clover strains were excellent hosts to all the root-knot nematode populations and races tested. SC-1, a germplasm, appeared moderately tolerant to race 1 and race 4, and 'Louisiana S-1', a cultivar, appeared moderately tolerant to race 2.

Warm-season cover crops grow during warm periods when plant-parasitic nematodes are most active. Some of these plants show marked resistance to several important pest nematodes. In the southeastern U.S., Rhoades (1980, 1983, 1984), Reddy et al. (1986), and Rodriguez-Kabana et al. (1988a, b) have shown that warm-season cover crops can be valuable in suppressing nematodes that might otherwise seriously damage succeeding cash crops. **American jointvetch** (*Aeschynomene americana*), **cowpea** (*Vigna unguiculata* ssp. *unguiculata*), and **hairy indigo** (*Indigofera hirsuta*) appear promising for reducing root-knot and soybean-cyst nematode. Hairy indigo can also reduce lesion nematode and sting nematode.

Other warm-season, tropical legumes, such as *Concanavalia ensiformis* and *Crotalaria* spp. reduce nematode numbers. **Sunn hemp** (*Crotalaria juncea*) reduces soil populations of several different species of plant-parasitic nematodes, including the root-knot nematodes (Good et al., 1965; McKee et al., 1946; Roman, 1964; Rotar and Joy, 1983).

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(DEC.270)

Spring 1991 (v2n2)

Fertile soil: A Grower's guide to organic and Inorganic fertilizers.

Parnes, Robert

Ag Access, Davis, CA. 190 pp.1990

This book addresses two common questions from growers: 1) *What fertilizer should I use?* and 2) *How much should I apply?* Parnes has a clear bias in favor of natural organic substances. For him, the plant and animal derived materials are important for maintaining soil quality: They are a direct source of nutrients, and they supply energy to organisms which maintain soil structure and fertility. Parnes acknowledges that organic residues cannot always supply the necessary nutrients and that there will be instances when synthetic fertilizers will be required, for example, when soils are chronically low in a particular nutrient or when making the transition to an organic production system.

A number of guidelines are included to help farmers answer questions about fertilizers for themselves. These guidelines are organized into the following decision-making framework:

Look first at whether any fertilizer is necessary at all.

- If there is a need, determine how much of each nutrient should be supplied.
- Lastly, decide what kind of fertilizer to apply-- organic, inorganic (mineral), or synthetic.

Soil Fertility

The question of whether fertilizer is necessary relates directly to soil fertility, i.e. the soil's ability to supply nutrients for crop growth and reproduction. Organic matter (carbon), air and water are the key components of soil fertility. Organic matter is the fuel for microorganism activity. It improves the cation exchange capacity, structure, and water holding capacity of soils. In addition, organic matter is an important reservoir for nutrients that are released slowly during the process of decomposition. The air-water balance in soil is important for maintaining a favorable environment for microorganisms, as well as for root growth and associated biological processes including organic matter decomposition, nutrient uptake and photosynthesis.

According to Parnes, there are two goals for increasing soil fertility: First, increase biological activity. This requires adequate warmth, aeration and moisture, a near neutral pH, growing plants and organic residues. Second, build a stable humus content. This can be accomplished with additions of fresh residue, and minimal cultivations (soil tillage increases the rate of humus decomposition.) Increasing organic matter levels can be a difficult task in some areas, but four methods are discussed. In increasing order of effectiveness: 1) add animal manure; 2) add straw or other high carbon residues; 3) add compost; 4) grow a sod cover. Succulent, green manures have relatively high amounts of nitrogen and are readily decomposable. They are, therefore, not as effective at improving soil organic matter levels.

Nutrient Requirements and Soil Nutrient Supply

When soil fertility is low, a farmer must then compare the nutrient needs of the crop with the amount of nutrients the soil can actually supply. Although the quantity of nutrients used by a particular crop is variable from year to year (depending on environmental conditions and yield), general figures on crop nutrient consumption can help determine potential nutrient requirements. To this end, Parnes includes an extensive table showing amounts of nitrogen, phosphate, potassium and sulfur removed by various crops at average yields.

The actual amounts of nutrients supplied by a particular soil can be determined from soil tests, tissue analyses, and/or personal experience and observation. Each of these methods can be used to complement the others and, in conjunction with good record keeping, help growers develop sound fertilization practices.

Organic Fertilizers

Once a grower has figures for crop nutrient requirements and soil nutrient supply, the choice of fertilizer is somewhat simplified: some fertilizers will be better at meeting those needs than others. Parnes presents an informative summary of the advantages, disadvantages and management of various materials. He first discusses **unprocessed residues** focusing on manure, and hay or straw. The key point with these "raw" materials is that they are still subject to rapid decomposition and loss of nutrients and should be handled to keep those losses to a minimum. Parnes sees **compost** as a particularly useful material and assigns it its own chapter. The unique features of compost which make it a good fertilizer, are its consistent and ideal C/N ratio (about 15-20:1) combined with a high concentration of minerals. Other aspects of compost production and management are also included. A third section on other organic fertilizers contains information on cover crops, organic by-products and processing wastes, commercial organic products, and soil activators.

Nutrient-Specific Information

This last section of the text contains some of the most pertinent information for growers. For each nutrient (nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium) Parnes discusses: 1) the importance of the nutrient to plants and the results of an excess or deficiency; 2) the behavior of the nutrient in the soil and how to make the most of soil reserves; and 3) appropriate organic and inorganic fertilizers that supply the nutrient. Fertilizer information includes cost comparisons, advantages and disadvantages, and comments regarding application rates. Parnes' analysis of nitrogen fertilizers is shown in Table 1. The book contains similar tables for phosphorus and potassium.

Table 1. Comparison of Selected Nitrogen Fertilizers

MATERIAL	N %	Characteristics Energy Index	C/N ratio	Value N	Total Value --$/Ton--	Typical Cost
Manure						

Cow	0.5	20	18	3	21	5
Pig	0.6	18	14	4	26	5
Poultry	1.5	20	7	9	37	7
Compost	1.2	40	17	8	61	varies
Hay						
Legume	2.5	78	16	16	105	
Non-Leg.	1.3	81	32	8	100	62
Alfalfa						
Pellets	2.7	82	15	16	114	244
Fish Meal	9.0	80	4	57	154	640
Synthetic				--$/100 lb--		
Urea	43	0	0	13.50	13.50	13.50
Amm Nit	33	0	0	10.36	10.36	12.50

a/ Energy Index: gallons of #2 fuel oil required to equal the energy supplied by one ton of material.
b/ Total Value = Value of N + value of P & K + value of energy where N is valued at $0.31/lb, P at $0.25/lb, K at $0.17/lb, and energy at $1.03/gal #2 fuel oil.

Fertile Soil is available for $29.95 from access, 603 4th Street, Davis, CA 95616 (Tel.530/756-7177). It includes 26 Tables total, plus appendices, references, an index and a glossary of terms.

(DEC.271) *Contributed by Dave Chaney*

Spring 1991 (v2n2)

The role of spray oils in alternative agriculture.

Davidson, Nita

Article written for Components 1991

Editor's note: The following is adapted from a forthcoming manual **Managing Insects and Mites With Spray Oils** *produced by the UC Statewide 1PM Project and published by the UC Division of Agriculture and Natural Resources. The manual emphasizes use of narrow-range spray oils during the growing season and includes tables suggesting correct timing and rates of oil sprays for a variety of crops. Publication authors are N.A. Davidson, J.E. Dibble, M.L. Flint, P.J. Marer, and A. Guye. The manual can be purchased from UCANR Publications summer 1991.*

Oil sprays have been used for pest control for over a hundred years, although their use in the late 1800s and early 1900s was limited primarily to dormant sprays. This was because the oils available then were kerosene emulsions and poorly-refined oils that often damaged actively-growing plants. The spray oils in use today rarely cause phytotoxicity, and are now effectively used during the growing season to control a wide array of insect and mite pests on deciduous fruit trees, citrus trees, and ornamental trees and shrubs. Most oils currently registered for use in the United States are petroleum distillates, although cottonseed and other plant-derived oils may be used more in the future. Mineral oils, horticultural spray oils, and citrus oils are all terms that have been used to describe various types of spray oils.

Interest in oils has resurged since the 1970s and 1980s due to widespread concern about the environmental and health hazards of synthetic chemical pesticides. Since the development of narrow- range oils in the mid-1960s, the number of crops and crop stages that can be safely sprayed has increased because these oils are far less damaging to plants (Chapman et al., 1%2). When label directions are followed, these newer oils can be used during the growing season without danger of phytotoxicity. In addition, narrow-range oils control several pest species besides scale insects and mites, which were the traditional targets of oil sprays.

Advantages and Disadvantages

Oils have several advantages over conventional pesticides because they: 1) possess a wide range of activity against most species of scales and mites, and some species of psyllids, mealybugs, whiteflies, leaf-hoppers and young caterpillars; 2) are also effective on eggs of mites, aphids, and some moths; 3) induce little or no resistance by target pests; 4) are usually less harmful to beneficial insects and predatory mites than other pesticides with longer residual activity; 5) are easy to use in the field, inexpensive, and safe to handle, and are relatively harmless to humans, other mammals, and birds; and 6) dissipate quickly after spraying, leaving little or no residue on crops. In addition, oils can be used on woody plants by certified organic growers.

Some problems may arise from the use of oils because they: 1) produce phytotoxic symptoms if applications are made when plants are weakened from infestations or diseases or otherwise under stress; 2) kill only insects and mites that are directly exposed; .3) achieve effective pest control only by a very thorough and precisely-timed coverage; 4) kill any exposed predatory mites or beneficial insects; and, 5) are not always labeled with sufficient information such as dosages of oil for high and low volume sprays, or the amount of oil applied per acre. Also, there is a lack of complete data on the effectiveness of pest control, effects on beneficials, and conditions of phytotoxicity.

Types of Oils Used in Pest Management

When narrow-range oils were introduced in the mid-1960s, many of the commonly-used terms to describe oils became redundant or obsolete. Nevertheless, some of these outdated terms are presently in use. For example, dormant and summer oils were originally defined by their distillation properties, but are now defined by the time of application. "Superior" spray oils are actually lighter summer spray oils developed in the 1940s; the majority of products presently on the market are of this type and can be used throughout the year without danger of phytotoxicity. Superior oils have undergone several state-of-the-art modifications over the years and are now commonly called narrow-range oils (Chapman, 1967). The "narrow-range" refers to the narrow distillation range of highly refined oils under vacuum (10 mm Hg). Narrow-range oils are generally safe to use as dormant or inseason foliage sprays on various crops provided spray recommendations and certain precautions are followed.

Dormant emulsive oils, once popular as dormant sprays for deciduous fruit and nut trees, are now not commonly recommended. Vegetable oil products are thought to have the same mode of action as petroleum oils, but they are generally more toxic to insects because of their fatty acid content, corresponding to the unsaturated hydrocarbons in petroleum oils.

Insect and Mite Control

Oils kill insects, mites, and eggs of both by contact. The pest dies only if present at the time of application; pests migrating to a recently-treated plant are usually unaffected by oil residues. The pesticidal action of oils is mainly physical, but may also be chemical. Mechanisms of toxicity include suffocation by blockage of the respiratory openings, which reduces the availability of oxygen and prevents exchange of gases for metabolic processes; and penetration and corrosion of the air passages, muscles, and nerves, which impairs physiological processes. Oils also have a repellant action, discouraging egg deposition and feeding, and the residual film may inhibit scale crawlers from attaching to plant tissue (Trammel, 1965). Antifeedant properties of oils have also been documented for the euonymus webworm (*Yponomeuta multipunctella*) and a leafroller (*Archips* sp.) on dogwood (Baxendale & Johnson, 1988).

Oils applied during the growing season have successfully controlled adults and crawlers of scale insects, phytophagous mites and their eggs, mealybugs, aphids, adults and nymphs of pear psylla, nymphs of grape leafhopper, eggs of oriental fruit moth and codling moth, and various stages of other moths. Oils applied during the dormant season are used to control scale insects, mites, mite eggs, aphid eggs, and pear psylla. Some control has been obtained on leafhoppers, whiteflies, true bugs, and thrips, and on sawfly larvae, non-hairy caterpillars, and beetle larvae.

When used for controlling scale insects, oils have advantages over other spray materials. Oils can be effective late in the summer when the outer body coverings of the scales have begun to harden, while most other products are effective only when scales are in their crawler stage, which is often in early summer. Scales are particularly susceptible to oils during the period of early crawler activity when their metabolic rate is high.

Butler & Henneberry (1990) have recently tested various vegetable oils as a spray for mites, aphids, and whiteflies on vegetables, cotton, and nursery plants. In addition to cottonseed oils, other vegetable oils tested include coconut, corn, palm, peanut, safflower, soybean, and sunflower. The cottonseed oil (Natur'l Oil, Stoller Chemical Co., Houston, TX) reduced numbers of spider mites (*Tetranychus* spp.) and sweetpotato whitefly (*Bemesia tabaci*) and controlled green peach aphid (*Myzus persicae*) and cabbage aphid (*Brevicoryne brassicae*) to some extent. The limiting factor was adequate coverage.

Complete coverage is important for good pest control because there is no residual toxicity of oils against insects. The pests must be covered with a film of oil in order to be killed. More effective control can be attained with improved coverage, particularly in the central area and the top of trees, rather than with increased dosage. The most important part of calibration is getting complete coverage and the correct amount of oil applied and spread over the leaves, fruit, twigs, and branches.

Effects on Beneficial Insects

Because of their short-term residual activity, spray oils do not severely affect populations of beneficial mites or insects, although most predators and parasites are killed on contact when sprayed directly. The impact of spray oils on beneficial species probably varies depending on the mobility of the species and its ability to reinvade sprayed areas from other locations. One study by Davies and McLaren (1977) showed that California red scale (*Aonidiella aurantii*) could be adequately controlled in orange trees by spraying 10 to 30 percent more oil on the outside canopy than within. Because A. *aurantii* is distributed more heavily on the outside of the tree, most of the scale population was controlled, leaving a small scale population and a reservoir of immature parasites, *Aphytis melinus*, within the canopy of the tree. Other studies have demonstrated a marked upset in the host-parasite balance for several years after thorough spraying with oils, so leaving a small population of parasitized and unparasitized hosts may be good insurance for future infestations. Beneficial insects can probably be released in the field or orchard a few days after an oil application, or perhaps once the oil film has dried (Campbell, 1975).

Only a few studies have specifically looked at the impact of spray oils on predators. In Fresno County, spray oil applied in early August (1977) to almond trees at a rate of five percent (five gallons oil in 95 gallons of water) did not significantly reduce the population of western predatory mites [*Galandromus (Metaseiulus) occidentalis*] or sixspotted thrips (*Scolothrips sexmaculatus*) up to 24 days following treatment (Dibble, 1977). When narrow-range oil was applied to citrus to compare the effect of various acaricides on natural enemies such as the predatory mite *Eusieus stipulatus*, its fecundity in the sprayed and unsprayed treatments was not significantly different (Morse et al., 1987).

Oils can be toxic to honey bees; they are temporarily inactivated and may be killed by direct contact. Spraying early in the morning before bees are active will reduce exposure. Beneficial insects such as lacewings, syrphid flies, or lady beetles often visit flowers on trees and shrubs to drink nectar. Sprays are best avoided during peak times of flowering, which varies according to the species of beneficial and plant.

How to Use Oils Safely on Plants

Most trees are generally not injured by narrow-range oil sprays. However, if spraying recommendations are not carefully followed, natural plant processes may be inhibited depending on oil quality and quantity, frequency of application, and stage and condition of the plant. Oils can damage plants by blocking stomata or lenticels, thus impairing C02 absorption, respiration, and transpiration, especially when heavier oils are involved. Oils also may increase plant injury if applied close to freezing weather. When oils penetrate plant membranes they may kill cells, leading to yellowing or chronic injury of the foliage. Older, heavier oils applied during the summer may darken the bark, thereby increasing heat absorption, and leading to sunburn, especially on younger trees. Phytotoxic side-effects from oils such as leaf drop, dead twigs and branches, and fruit drop were much more common when the older wide-range oils were in use.

Injury includes damage to bark, foliage, and fruit peel such as russetting and water spotting. The most frequent symptoms are marginal leaf burn in spring and summer, and twig dieback from dormant sprays. Bark injury may occur on twigs and cause spotting on the inside of the thin bark, only visible if the bark is peeled off with a knife. Oil sprays can make navel oranges more susceptible to "water spot" which results from penetration of water into the rind. Applying excessive amounts of oil or spraying at inappropriate times may result in proliferation of lenticels on the skin of pears, water-spotting of almond leaves, or spotting on the waxy surface (bloom) of plums and grapes. Cold injury to plants can be increased by badly-timed oil sprays.

Studies on phytotoxicity from oil sprays usually attribute damage to user error (Johnson, 1985). Although fewer problems occur with narrow-range oils, and deciduous fruit and citrus trees are relatively hardy, several precautions should be taken. Lack of moisture, extreme temperatures, sudden change in temperature after spraying, prolonged winds, or poor conditions due to disease or heavy pest infestation will predispose the plants to phytotoxicity. Labels accompanying spray oils list specifications regarding compatibility with other materials. Oils are not compatible with sulfur and should not be sprayed less than 30 days before or after a sulfur application or severe phytotoxicity may result. Heavy pest infestation will predispose the plants to phytotoxicity.

Effectiveness of Spray Oils

Performance and safety of spray oils varies among species of plants. Many relevant studies to date are unpublished or not widely available; some information is merely observational. More accessible information would be helpful to confirm the susceptibility of certain cultivars or species to phytotoxicity, or suggest the most appropriate time to treat a particular pest. To complicate this problem, studies are performed with regional variations of temperature, humidity, rainfall pattern, soil, and pest pressure. Within a specific region, factors such as coverage, rate and type of oil used, and density of natural enemies will vary. Also, after years of standard spray programs for perennial crops such as nuts, deciduous fruit trees, and grapes, some pests become more difficult to manage due to resistance and low numbers of natural enemies. Over time, pest management programs using oils may prove to be even more effective than shown in initial trials because of later buildup of natural enemies. For this reason it would be worthwhile to study the effectiveness of spray oils in relatively undisturbed sites. In addition, evaluation would be more useful if established damage thresholds were used, and amount and quality of crop yields compared among treatments. The UC-IPM publication on which this article is based describes a variety of experiments evaluating the performance of oils to manage pests of fruit and nut trees, citrus, grape, ornamental trees and shrubs, vegetable and field crops, and greenhouse plants.

Health and Environmental Effects

Oils are relatively non-toxic compared to synthetic pesticides, with very high oral and dermal LD5OS. Narrow-range oils are similar to the mineral oils used in most skin lotions and baby oils, and to pharmaceutical grade oils taken internally as purgatives. However, care should be taken when using oils, and safety precautions listed on the label observed. The paraffinic portion of spray oils do not contaminate air, soil, or water. However, within the unsaturated hydrocarbon portion (no more than 10 percent by weight), some of the aromatic contaminants that may be present in minute quantities are known to be carcinogenic. Also included are trace impurities of sulfur and nitrogen compounds, and the toxicologically important polyaromatic hydrocarbons (PAHs), also known as polynuclear aromatics (PNAs). These compounds usually occur at concentration levels of only parts per billion or trillion, but some are known to be carcinogenic. Currently, the petroleum industry is trying to eliminate PAHs in the finished product.

Spray oils applied at normal rates are unlikely to be detrimental to wildlife. However, during the dormant spray season when spray oils are combined with organophosphates for some dormant sprays of tree crops, an increasing number of raptors have been brought to wildlife care centers with specific symptoms of organophosphate poisoning. Studying red-tailed hawks trapped around sprayed orchards, researchers found pesticide residues on feathers and feet, abnormal concentrations of pesticide metabolites in excreta, and lowered levels of blood cholinesterases (Hooper et al., 1989). In studies now in progress, hawks are being tracked during the dormant spray season to assess levels of toxicity and to design ways to mitigate the problem. This may indude changing application methods, finding safer rates of organophosphates to use, and examining the behavior of hawks during the spray season. It is unknown whether the hawks are directly contacting organophosphates on sprayed surfaces, or are being poisoned by eating contaminated rodents. However, use of oils alone during the dormant season is not likely to have negative impacts on raptors.

Future of Spray Oils

In recent decades, the fluctuating supply of petroleum has affected the availability and price of spray oils. Before this time, crude oil with particular properties could be specified for production at a planned time. This is no longer possible, and some types of spray oils have had to be phased out due to shortages, economic changes, or production attitudes.

New methods of analysis of specifications for spray oils are currently being developed. For example, gas liquid chromatography may represent the distillation midpoint of an oil more accurately than distillation at l0 mm Hg (Furness et al., 1987). More attention to climatological detail and a basic understanding of plant physiology are required to successfully use oils on a more widespread basis. Much progress has been made recently in producing spray oils that combine low phytotoxicity with high insecticidal effectiveness. Despite the need for more research on how oils can be used most efficiently, they remain one of the safest and relatively cheapest insecticides and acaricides, and are still very much under-utilized.

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