Winter 1992 - Vol. 3, No. 1

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Winter 1992 (v3n1)

Yellow starthistle control.

Thomsen, Craig and WA. Williams

Adapted from Range Science Report, No. 30. Department of Agronomy & Range Science, University of California, Davis. 1991

Yellow starthistle, *Centaurea solstitialis*, is a plant of Old World origin that probably arrived in California in the mid-1800s as a contaminant in alfalfa seed. Since its arrival it has steadily spread and now inhabits about 8 million acres statewide. Yellow starthistle is one of California's worst noxious weeds, infesting rangelands, pastures, hayfields, orchards, vineyards, roadsides, canal banks, and parklands. It has many traits that make it a successful weed including: 1) a large seed output, 2) seeds that germinate over a long period of time, 3) a deep taproot, 4) late spring and summer growth, 5) an ability to quickly regrow after mowing or grazing, 6) and spines that discourage grazing in the reproductive stage.

Life Cycle and Plant Description

Understanding the basics of yellow starthistle biology, and recognizing the various stages of growth are necessary when attempting control. Yellow starthistle has a very long life cycle for an annual plant. Germination is initiated by autumn rains, but plants mature long after most other annuals have completed their life cycle, sometimes not completing their life cycle until late summer or fall. In addition, successive germination occurs long into the growing season.

The seedling stage is the most difficult time to identify the plants. A good way to learn to recognize them is to first locate seedlings under older starthistle skeletons that remain in the field from the previous year's growth. The winter and spring rosettes produce many deeply-lobed leaves. Although there is variability in the size and lobing pattern of the rosette leaves, a good diagnostic character is the large terminal, triangular lobe at the tip of each leaf In general, the rosettes tend to grow close to the ground in open places, but assume an up-right habit when there is an abundance of neighboring vegetation.

During May and June the plant "bolts" and sends up stalks, which give rise to the flower heads. The mature plant reaches a height of one to three feet. The gray-green to bluish-green stems of the mature plant are widely branched, and the entire plant is covered with soft, appressed hairs. Rigid spines project from the bracts that surround the bright yellow flowers.

The seed development stage can be recognized by the absence of the bright yellow pigment that characterize the younger flowers. Two types of seed are produced. The light-colored disk seeds (central portion of the flowerhead) contain short bristly hairs and are dispersed quickly after maturity. The outer seeds lack hairs and persist for months, remaining in the flower heads until harsh weather or some other disturbance breaks them up. The number of seeds produced by individual plants varies widely according to environmental conditions and genetic factors. In studies of starthistle populations from Hopland, Woodland, and Concord, Maddox (1981) reported a range of about 700 to 10,000 seeds per plant. Once seeds are dispersed, many become part of the soil's "seed bank" where they remain until conditions become favorable for germination, or are eliminated through natural means.

Control Considerations

There is no simple recipe for controlling yellow starthistle, and any control program will require a systematic and persistent effort that may take several years or more. The approach that is taken will depend upon such factors as the size of infestation, plant density, location, equipment available, and planned use for the site.

When planning a control program determine whether you are aiming to **eradicate**, **manage**, or **contain** yellow starthistle. Eradicating means to eliminate starthistle from the site, and requires that seed production is halted and the seed reservoir in the soil from previous years is depleted or managed in a way so new seedlings don't survive. It is impossible to completely eradicate large infestations. With persistence and good management, however, dense stands can be reduced to tolerable levels.

Containment is done by delineating boundaries around large infestations and concentrating control efforts on the smaller occurrences that exist outside of the contained areas. By controlling isolated plants or small patches that are the "pioneers," the larger infestation is contained and further weed spread is prevented. As information and experience are gained from controlling small occurrences, better decisions can be made about whether larger areas can also be successfully controlled.

Become acquainted with starthistle's ecology as it applies to your situation. This will enable you to better assess what cultural practices may be encouraging its proliferation. Often, weeds invade and persist in areas because management practices create ecological "voids" that are exploited by invading species. If a species is controlled, but the void remains unfilled, reinvasion will occur by the targeted species or by a different one that may be equally troublesome. In an ecologically-based control program, the replacement of an unwanted "pest" species by desirable species should be a key consideration.

Timing control efforts to various stages of plant growth is absolutely essential. Figure I lists some control measures placed according to stage of starthistle growth. Some of these can be used during several growth stages, but all of them should occur before seed production. Due to weather patterns, site differences and genetic variation, the duration of life cycle stages depicted by the bars will vary considerably. Thus, on-site monitoring is necessary and control activities should be performed accordingly.

Control Methods

There are six categories of control including mechanical (tillage, grubbing, or mowing), fire, chemical (herbicides), biological (insects, plant competition, and live-stock grazing), preventive, and integrated control. The various methods discussed below are based on established principles of weed control, research, and anecdotal information. Research is incomplete, but studies are underway to fill some of the information gaps.

Mechanical. Cultivation with appropriate implements as the seedlings emerge in the fall is an excellent means of removing young plants. On sites where irrigation is available, infested areas can be pre-irrigated prior to autumn rains and then disked to remove germinating seedlings. If this sequence is repeated, much progress can be made in reducing the seed bank. Deeper cultivation in the spring will eliminate well-developed plants for that season. But deep tillage will bring weed seeds to the surface so expect more plants to germinate with the onset of autumn rains.

Hand-weeding or "grubbing" with a hoe or a weed-eater to control yellow starthistle in small areas should not be overlooked as an important part of any integrated weed control program. The easiest time for this is during the seedling or early rosette stages before the taproot has become well-developed. As the plant develops, its potential to regrow from the taproot is increased, and the upper portion of the taproot will need to be dislodged. Periodically monitor the site for more germination or re-growth.

Mowing is a useful method in managing yellow starthistle provided it is well timed and repeated as necessary. Although no replicated studies have been done, preliminary studies indicate that when starthistle is mowed during the early flowering stage regrowth is minimized. Mowing at this stage removes the aerial portion of the plants after much of their root reserves has gone into producing flowers; therefore, less reserve is available for regrowth. Under low soil moisture conditions, this single-event mowing may be sufficient, but plants should be monitored for regrowth and mowed again if significant growth and flowering occurs. When mowed at earlier stages, regrowth should be expected and several additional mowings will be necessary.

All mowing should be done prior to seed production. As mentioned previously, flower pigmentation is a good way to monitor whether seed development has commenced, but if in doubt open a flower and check for mature seeds. If the flowers are bright yellow and have not faded, seed production has not occurred. Mowing after seeds have been produced removes the hedge-like canopies but does not diminish the seed bank and may aid in seed dispersal. In general, mowing will be most effective when soil moisture is low and no irrigation or rain-fall follows the mowing.

Prescribed Burns. In some situations prescribed burns may be an appropriate management tool. The best time to burn is probably the same stage recommended for mowing. Since starthistle is still green during this period, there must be enough dry biomass from other annual plants to carry a fire. Burning permits are available through the California Department of Forestry (CDF).

Chemical. There are many types of herbicides available, most requiring a permit from your County Agricultural Commissioner. If you are unfamiliar with herbicide use, refer to UC Cooperative Extension publication No.1919, *Selective chemical Weed Control* for specific information. Before using any chemical, carefully read and follow precautions on the label. With yellow starthistle, seedlings are killed by herbicides but new plants will germinate with additional rains. Therefore, post-emergent herbicides are best applied in spring, after the rainy season, when temperatures are warm, soil moisture is high, and plants are actively growing in the late seedling or rosette stage. Non-selective herbicides, like glyphosate, are effective for spot treatments. However, since glyphosate kills nearly all other vegetation, treatment with this chemical is not usually suited for use over large areas. Selective herbicides such as 2,4-D will help control yellow starthistle and leave grasses unaffected. Care should be taken because these materials will also partially control legumes and other broadleaf plants that may be useful to the ecosystem or production goals. In pastures, a 30~ay waiting period is required before animal grazing can be resumed.

Biological Control & Grazing. Insects and a rust pathogen to control yellow starthistle are currently being evaluated to determine their effectiveness in controlling starthistle populations. Field releases have been made and some appear promising, but additional time is needed to assess the long-term effects of the various biocontrol agents.

Livestock routinely graze yellow starthistle before it becomes spiny, and nutritional studies have shown that it is an acceptable component of a ruminant's diet. Well-timed controlled grazing with cattle has been demonstrated to be an effective method for managing large stands of yellow starthistle in annual rangeland (Thomsen et al. 1989, 1990). For three consecutive years, **intensive cattle grazing** (high stocking densities with short grazing periods facilitated by portable electric fencing) reduced plant densities and seed production in the dense starthistle stands under study. Spiny canopies persisted through summer and fall in the ungrazed paddocks but were greatly diminished in the grazed areas. Grazing was initiated in mid-to late-May after many other resident annual plants had completed their life cycle and produced seed. Since yellow starthistle was green and palatable at this time, animals readily defoliated plants, making use of it as a forage.

The most effective control of yellow starthistle is obtained when grazing occurs during the stem elongation and early floral bud stages, and is repeated several times to remove the regrowth. Most defoliated plants recover quickly, and if rotations are used, animals should be put back about two weeks later to regraze the plants. The actual number of grazings required varies according to soil moisture levels. Thus, the amount and timing of rainfall has a strong influence on starthistle recovery.

Observations from other sites where continuous **low-density grazing** is practiced indicate that if sheep, cattle, and/or goats are present in sufficient numbers during the late stages of growth and grazing pressure is maintained, animals utilize the plant and also suppress it. On the other hand, if grazing occurs when starthistle is in the rosette stage but is not continued during bolting, yellow starthistle tends to be favored relative to other herbaceous vegetation. Along with yellow starthistle, neighboring plants are also defoliated, and the competition they provide is eliminated. Yellow starthistle's ability to regrow following defoliation exceeds most, if not all other annual plants on California dryland pastures and ranges.

Grazing yellow starthistle is not a viable control option in horse pastures. When eaten by horses in sufficient quantities, it can lead to a potentially fatal disease of the nervous system called "chewing disease." The nature of the disease is such that the plant may be ingested over a period of years before any symptoms are apparent, and at that point it is irreversible.

Preventive. Preventive weed control measures generally refer to doing what is necessary to stop the introduction of new weed species to a specific area. As in containment programs, this includes detection and control of "pioneer" plants before they go to seed along roadsides, fields, pastures, etc. and develop into large infestations. Because spot occurrences and small colonies seem harmless, the tendency is to overlook them; however, this is the way most large infestations begin. Even though yellow starthistle is widespread, there are still many portions of the state where it has yet to invade, but would be well-adapted.

Integrated Control

A combination of control methods will generally be the most effective way of controlling yellow starthistle. A good example is in agricultural areas where starthistle is often absent in cropland, but abundant as a border vegetation between the fence line and roadside. The frequent cultivation and use of herbicides in conventional crop-ping Systems reduces the seed bank and prevents yellow starthistle from reaching maturity.

Combining native perennial grasses and herbicides has potential to suppress starthistle and other weeds that occur in drainage ditches, along roadsides, and borders of agricultural lands. Researchers from UC Davis are currently evaluating different native perennial grass species and herbicide applications to achieve this objective. The aim of this research is to use selective herbicides to aid in grass establishment, and reduce herbicide use to periodic spot treatments once the deep-rooted grasses become established. When herbicide use subsides, broad-leaf plants such as lupines, poppies, and other wildflowers can be incorporated into the system. The investigators view this as a means not only to control weeds, but also to create wildlife habitat for quail and pheasant, improve the aesthetics of the rural landscape, integrate biological diversity onto agricultural lands, and reduce the $40,000 a year ($100.00 per mile) spent on roadside weed control in Yolo County (Bugg, et al., 1991). [See also *Components* 2(1), 1991.]

According to Bob Roan of the US Soil Conservation Service, lana vetch was used as a competitor against yellow starthistle. In a several acre trial, Roan reported that starthistle was suppressed by the aggressive, sprawling growth of the vetch, and the starthistle that survived was weak. Mixing a robust grass such as Merced rye, red oats, or Briggs barley with the vetch would add an additional measure of competition to further crowd out starthistle. Using a no-till drill allows seeding without turning the soil, and helps keep deeply buried seeds from germinating. A well-timed mowing could be used in combination with the seeding, which would add another stress to starthistle at a critical stage of growth.

These are a few of the many possible combinations that are options for controlling starthistle. Regardless of what methods are used together, effective long-term control requires that 1) seed production is halted, 2) plants emerging from the seed bank are eliminated, and when possible that 3) other, more competitive plants be permanently established that match the ecological niche filled by starthistle to prevent reinvasion.

Conclusion

Although yellow starthistle is a troublesome weed, its useful properties should not be overlooked. Starthistle is a valuable source of summer nectar for bees, and honey produced from it is a premium quality. Yellow starthistle's early and late-season growth, palatability, and resilience make it a useful forage plant to ruminant animals before it becomes spiny. It provides food and cover to wildlife, especially small mammals and birds. Bill and Helga Olkowski of the Bio-Integral Research Farm in Winters have found that the cut stalks and seed provide a supplementary food for their chickens. Also, as an aggressive, colonizing species, starthistle rapidly covers and helps stabilize unprotected soil.

Despite these useful qualities, yellow starthistle remains a significant pest for most farmers and landowners. The stout spines and hedge-like stands of yellow starthistle that remain through summer and fall, and its invasiveness make controlling it a necessary task. It has been estimated that since 1958, yellow starthistle infested land has increased from 1.2 to 7.9 million acres, an increase of 640 percent (Maddox 1985). Yellow starthistle will continue to increase statewide and will be particularly prominent in years with abundant late-season rainfall.

Ongoing research efforts on yellow starthistle control include seed bank studies, mowing, and goat grazing at the UC Davis Agronomy Farm; seed bank studies at UC Sierra Field Station; the use of native grasses in combination with herbicides along roadsides in Yolo County; and biological control at USDA-ARS, Albany, California (contact Dr. Charles Turner).

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(DEC.329) *Contributed by Craig Thomsen and David Chaney*

Soil solarization.

Katan, J. and J.E. DeVay (eds.)

CRC Press, Boca Raton, FL. 267 pp. 1991

This new text, hot off the press, serves both as a review of the literature and as a handbook on the technological and practical aspects of soil solarization. University of California contributors include Carl Bell, Frank Laemmlen and Jim Stapleton (Farm Advisors-UC Cooperative Extension), James DeVay (Professor-UC Davis Plant Pathology) and Clyde Elmore (Extension Specialist-UC Davis Botany).

The book is divided into four sections. The first, *Soil Solarization as a Control Method*, provides an overview of the population dynamics of soil pathogens and reviews the types of organisms that can be controlled through solarization. Specific chapters in this section address the effects of solarization on pathogens, nematodes, and weeds. Section II describes the physical, microbial, and chemical changes in solarized soil that destroy or suppress various pests. The third section titled *Technology and Application*, reviews the material and technical requirements for successful solarization. This section also includes a chapter on the economic evaluation of soil solarization. Section IV is titled *Implementation of Soil Solarization in Different Cropping Systems*. The chapters in this section report how solarization has been used in various locations worldwide. One chapter by UC farm advisors Carl Bell and Frank Laemmlen describes the use of soil solarization in the Imperial Valley. The book is priced at a steep $130.00, but if you are interested, it will soon be available at the UC Davis library.

(DEC.328) *Contributed by David Chaney*

Winter 1992 (v3n1)

Natural pesticides from plants.

Duke, S.O.

In Janick, J. and J.E. Simon (eds.) Advances in New Crops, pp. 511-517. Timber Press, Portland, OR. 1990

Reviewer's note: Sustainable agriculture maximizes the use of on farm biological controls. When off-farm materials are required, the inputs chosen must be effective, environmentally and toxicologically safe, economical, and when possible, derived from natural sources. Secondary products of plants, especially those involved in the defense of the plant from pests, are a largely untapped reservoir of natural compounds with pesticidal properties. While these materials may be equally toxic as their synthetic counterparts, their value (and one of their disadvantages) comes largely in their lack of residual activity. This chapter (with 25 references) is a review of plant-derived pesticides and the factors influencing their discovery and development.

Herbicides

Plant-derived herbicides are usually far less active than commercial herbicides. Highly phytotoxic plant compounds are not common because they could be lethal to the plant unless it developed adaptive mechanisms. While some highly phytotoxic plant chemicals have been identified, none have been developed as herbicides. Some plant compounds, such as hypericin, induce a toxic reaction in the presence of light, i.e. they are "photodynamic." Photodynamic compounds are not likely to be used as herbicides due to their toxicity to all living organisms. However, plants can be stimulated to generate their own photodynamic compounds. The contact "laser" herbicide is being developed for this purpose. This relatively safe combination of compounds causes weeds to produce phytotoxic levels of photodynamic porphyrin compounds. leading to self-destruction of the weeds.

Insecticides

Plant products are well known for their use as insecticides, insect repellents, and insect antifeedants. Several *Chrysanthemum* species produce pyrethroids, which have been used in Asian countries for centuries; pyrethrum is currently being used by many organic farmers and gardeners. Numerous synthetic pyrethroids have been developed; these are more active and have longer residual activity than the natural forms.

Several natural alkaloid substances have also been used commercially. These include nicotine, derived from *Nicotiana* species, and ryanodine, from the tropical shrub, *Ryania speciosa*. Carbamate insecticides were designed from physostigmine, an alkaloid in *Physostigma venenosum*. The use of alkaloid-based insecticides is very limited due to their high cost, toxicity to mammals, and limited efficacy.

Several plant phenolic compounds have insecticidal properties and have been correlated with host plant resistance to insects. Rotenone (derived from the roots of three genera: *Derris*, *Lonchocarpus*, and *Tephrosia*) was used commercially as an insecticide in the 1930s and is used by some organic gardeners today; no other phenolic compound has been used commercially as an insecticide.

Fungicides

Plants rely primarily on the production of secondary compounds for defense against pathogens; these chemicals are called phytoalexins. There is evidence that some synthetic fungicides act by inducing the production of phytoalexins in plants. Numerous phytoalexins have been identified and many have proven successful in tests against fungal infection of crop plants. Although several fungicidal and bactericidal compounds have been identified in plants, antimicrobial pesticides have not been developed to any significant extent.

Discovery and Development of Natural Pesticides

Because plants have evolved with natural mechanisms for protection, secondary compounds from plants are very likely to have activity against pests. But identifying these natural biocides is a difficult task-more difficult than identifying synthetic pesticides. The process is complicated by several factors, including the following:

- There are no guidelines regarding the amount of initial purification required for compounds.
- Only small amounts of secondary plant compounds are capable of being isolated. Thus, bioassays that use very small amounts of the compound are required.
- Structural identification of the compound can be very difficult for natural products.

Determining which pests may be controlled by compounds from a particular plant species can be made easier by identifying the pests to which the producing plant is resistant. Pyrethroid insecticides were discovered in this manner. While this process can be a major effort, some form of biological activity is likely; modern techniques for identification and purification are "shifting the odds in favor of natural compounds."

Development of highly efficacious natural pesticides can be as difficult as their discovery. Patentability of the natural compound can be an early obstacle, since prior publication of its pesticidal properties may cause patent problems. Toxicological and environmental studies are also required; natural pesticides often degrade rapidly in the environment, but many are highly toxic to mammals.

A major challenge is to find cost-effective means of producing natural pesticides. Various alternative methods of production are discussed in this article. For example, tissue or cell culture can be used, but genetic stability in the production of secondary products has been a problem. Furthermore, cells that perform the desired function of producing potentially autotoxic compounds may be selected against, unless specialized techniques are employed to remove or limit production of the toxins. Genetic engineering and biotechnology are also discussed as means to develop plant-derived secondary products.

For more information write to: USDA ARS, Southern Weed Science Laboratory, P.O. Box 350, Stoneville, MS 38776.

(CI-PEST.048) *Contributed by Chuck Ingels*

Winter 1992 (v3n1)

Harvest of hope: The potential for alternative agriculture to reduce pesticide use.

Curtis, Jennifer, Tom Kuhnle and Lawrie Mott

Natural Resources Defense Council (NRDC). 1991

The lack of national leadership to protect water resources from agricultural nonpoint source pollution, combined with the additional threats pesticides pose to the environment and public health, provides a strong argument for reducing the use of agricultural chemicals. Source reduction, as in other industries, is a logical, practical strategy for preventing the environmental problems associated with agriculture.

Widespread adoption of alternative agricultural practices holds the greatest potential for source reduction. These farming practices are designed to reduce chemical inputs, preserve and enhance natural resources, and protect human health. Alternative agriculture encompasses practices often referred to as biological, low (or reduced) input, organic, regenerative, and sustainable.

Potential Reductions in Pesticide Applications for Selected California and Iowa Crops

Despite the growing interest in alternative agriculture, broad implementation of these techniques has not occurred. This report seeks to illustrate the dramatic potential for alternative farming systems to reduce pesticide use. By obtaining information on alternative pest control strategies from published scientific literature, results of ongoing research, and experiences of individual farmers, this study projects potential reductions in pesticide applications for nine crops in California and Iowa. These crops were chosen to provide a cross section of the diversity of American agriculture.

The viability of alternative farming practices varies depending on weather and soil conditions and the management capabilities of individual farmers. In California alfalfa, border harvesting and strip cutting could potentially reduce insecticide applications by 30 percent. Intercropping of cotton in alfalfa could potentially decrease herbicide applications by 40 percent. Insecticide applications could potentially be reduced 50 percent in San Joaquin Valley citrus with greater adoption of integrated pest management (IPM). "Middles" management in citrus could potentially decrease herbicide applications by 40 percent. In California cotton, insecticide applications could potentially be reduced 25 percent with interplanting and IPM. Leaf removal could potentially reduce fungicide applications by 30 percent in California wine grapes. Insecticide and herbicide applications in California grapes could potentially be decreased by 35 and 50 percent, respectively, with a variety of alternative techniques. In California lettuce, greater use of 1PM and crop rotations could potentially reduce insecticide, fungicide and herbicide applications by 25, 20, and 50 percent, respectively. Adoption of a no-till/drill-seeding system, cover crops, and crop rotations could potentially decrease herbicide and insecticide applications by 50 and 25 percent respectively in California rice. In processing tomatoes, sub-surface drip irrigation, crop rotations and IPM could potentially reduce herbicide and insecticide applications by 50 and 25 percent. Banding herbicides, ridge-till, crop rotations, and a corn root-worm bait could potentially decrease herbicide and insecticide applications by 50 and 80 percent, respectively, in Iowa corn. In Iowa soybeans, banding herbicides, ridge-till, narrow row production, and strip intercropping could potentially decrease herbicide applications by 50 percent.

Barriers to Alternative Agriculture

Several barriers stand in the way of widespread adoption of promising alternative farming practices. In some areas, a scarcity of skilled labor makes it difficult to follow aspects of 1PM that require scouting and other labor-intensive activities. Weather-induced risks, such as heavy spring rains in the Corn Belt, can deter mechanical cultivation. Regional soil conditions can also make it difficult to adopt alternative strategies. For example, the heavy clay soils in certain rice-growing regions of California deter crop rotations.

Federal and state policies also hinder the adoption of alternative farming systems. First, the federal government is the hub of the huge agricultural research and extension complex that spends more than $1.5 billion each year. Yet alternative agricultural research is underfunded and dissemination of information about these techniques is inadequate. Second, many farmers receive a large portion of their income from farm subsidies disbursed by the federal government. However, the rules by which these payments are distributed prevent reductions in pesticide use by penalizing crop rotations and promoting surplus production and increased yields. Third, federal and state marketing orders and grade standards can result in unnecessary pesticide applications by specifying cosmetic criteria for produce that are difficult to attain cost- effectively without the use of chemicals. Fourth, current pesticide regulations hinder the rapid registration of biologically-based materials that could substitute for chemical pesticides. Fifth, the federal Bureau of Reclamation supplies growers in California and other western states with irrigation water at rates substantially below the true cost. Growers, therefore, are discouraged to invest in water conservation techniques that could facilitate reductions in pesticide use. Finally, the costs farmers now pay for pesticides fail to account for the impact of these chemicals on human health and the environment (so-called externalities). This makes pesticides incorrectly cheaper than alternative farming systems.

Recommendations for Reform

Policy reforms in six key areas are essential for eliminating many of the barriers to widespread adoption of alternative farming systems: agricultural research, federal farm programs, marketing policies, pesticide registration requirements, water pricing, and hidden costs of agricultural chemicals. To date, the development and implementation of agricultural techniques that reduce chemical use have been stymied by the lack of funds directed to alternative agricultural research. Funds for alternative farming research, particularly on-farm, systems- oriented research, should be substantially increased.

The federal farm programs reward farmers for producing a handful of commodity crops that tend to use large amounts of chemical inputs. The commodity programs should be amended so farmers can adopt more environmentally-sound farming systems without incurring financial penalties.

Federal and state marketing policies often make it difficult for farmers to adopt alternative farming practices that use fewer pesticides. Federal and state marketing orders should not be allowed to use cosmetic quality standards to differentiate produce. In addition, exemptions from marketing orders should be granted to all certified organic produce.

The development of biologically-based materials, such as botanicals, microbials, and pheromones has been obstructed by federal and state pesticide registration requirements. Congress should direct the National Academy of Sciences to review existing regulations for biologically-based materials and make recommendations for improving government procedures to hasten the registration of biologically-based pest control techniques.

The use of efficient irrigation systems has the potential to significantly reduce the use of agricultural chemicals and their transport to water supplies. However, because of the low price of irrigation supplies available to many growers, more efficient technologies and management practices have not been widely adopted. The U.S. Bureau of Reclamation should revise its water prices to encourage greater efficiency. Similarly, irrigation districts should adopt tiered water rate schedules that discourage inefficient irrigation practices and encourage the adoption of alternative farming systems.

Conventional agricultural practices rely extensively on the use of pesticides and fertilizers. However, current market prices for pesticides and fertilizers do not reflect the true environmental and social costs of their use. Federal and state governments should levy fees on the use of pesticides and fertilizers to reflect the environmental and health costs, and to provide revenues for alternative agricultural research and development programs, as is the current case in Iowa.

For more information write to: Natural Resources Defense Council, 90 New Montgomery Street, San Francisco, CA 94105.

(DEC.334)
Contributed by Jennifer Curtis
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Winter 1992 (v3n1)

Vitamin and mineral contents of carrot and celeriac grown under mineral or organic fertilization.

Leclerc, J., M.L. Miller, E. Joliet and G. Rocquelin

Biological Agriculture and Horticulture 7:339-348. 1991

This study adds to the body of research that compares the influence of organic production methods and conventional agriculture on the nutritional quality of produce. Specifically, this study focuses on the effects that the type of fertilizer- either organic or mineral-may have on the vitamin and mineral contents of carrot and celeriac (celery root). Zinc levels in both vegetables were also measured since an increase in the concentration of zinc may indicate agricultural or atmospheric contamination.

Methods

Twelve market gardeners using organic production methods were paired with twelve using conventional methods for each vegetable: carrots and celeriac (six pairs per crop in 1987 and a different six pairs per crop in 1988). Each pair was in the same geographical area (in the Burgandy area and in Dole, in the Jura region of France), had the same soil type, used the same variety, same growing period and when possible, the same sowing date. The organic or "biological" farmers used cattle or stable manures or commercial organic fertilizers, while the conventional farmers used manures and mineral fertilizers. The total nitrogen, potassium and phosphorus fertilizer added to the soil was calculated for each farm from information furnished by the farmers. At harvest, 5 kg of carrots or 12 celery roots were randomly collected from each field. Carrots or celery were blenderized, homogenized and divided into aliquots to determine mineral content (Ca, Mg, K, P, Cu, Zn, Fe, Mn, NO3 and total N), and vitamins (C, beta carotene, B vitamins and pantothenic acid). Vitamin and mineral determinations were averaged for the organic and for the conventional growers and reported with their standard errors (see Table 1). A two-way analysis of variance was performed on the results with the fertilization technique as one factor and blocks of farmer pairs as the second factor.

Results and Conclusions

Carrots. This study showed that the organically grown carrots were significantly higher ($P < 0.05$) in beta-carotene (+12 percent) and in vitamin B1 than those grown with mineral fertilizers. Other nutrients were not affected. These results agree with some, but not all of the previous research in this area. The data for beta-carotene is particularly variable. The authors note that since carrot beta-carotene is dependent on soil nitrogen, it is interesting that the organically grown carrots had higher beta-carotene levels since the organic farmers generally used less fertilizers than the conventional farmers. Thus, the authors conclude that cultural techniques appear to be the principal cause of the variation in beta-carotene content.

Correlations showed that vitamin B2, niacin, zinc, phosphorus, iron and manganese were positively correlated with weight, and nitrate was negatively correlated. Also, dry matter was positively correlated with Ca, P, Zn, Cu, Mg and Mn. Thus, for an equal growing period, the heavier the carrot, the higher its nutrient content and the lower its nitrate content. Yet, younger carrots are generally richer in many vitamins (except beta-carotene). The overall nutritional value of the carrot depends both on its "age" and its weight.

Celeriac. The study showed that the organically grown celery roots generally weighed less and had lower total nitrogen, nitrate (-56 percent) and zinc (-19 percent), but were higher in dry matter, phosphorus and vitamin C (+11 percent) than conventionally grown celery roots. The authors note that the zinc level was higher in the conventionally grown celeriac due to application of a zinc-based pesticide. Correlations showed that phosphorus was negatively correlated with weight, thus explaining why phosphorus was higher in the organic celeriac. Since nitrate did not correlate with either dry matter or weight, the authors conclude the difference observed was due to the fertilization method.

The authors conclude that the nutritional differences found in these two vegetables due to the use of organic fertilizer are significant. They recommend extending this study to other commonly eaten vegetables such as leafy greens and tomatoes.

Table 1. Mean weight, and selected vitamin and mineral contents (per 100 g. wet matter) for conventionally fertilized carrots and celeriac.

		Vitamins			Minerals			
Crop/ Production Method	Weight g	B-car mg	C mg	B1 ug	Ca mg	Fe ug	Zn ug	NO3 ppm
Carrots								
Organic (mean) (s.e.)	69 8	8.3* 0.4	4.5 0.5	43* 3	34.4 1.3	408 85	387 48	413 86
Conven. (mean) (s.e.)	69 6	7.2* 0.4	3.8 0.4	36* 2	36.8 2.7	404 45	485 65	433 86
Celeriac								
Organic (mean) (s.e.)	467* 42	- -	8.1* 0.5	33 4	39.6 2.2	792 75	467* 38	250* 42
Conven. (mean) (s.e.)	617* 58	- -	7.3* 0.4	36 4	41 2	798 90	577* 44	572* 125

* For each parameter and crop, means with a * are statistically different (P<0.05, Newman-Keuls test.)

Reviewer's Comment

Although the authors conclude that organic fertilization methods improve the nutritional quality of carrots and celeriac, it is difficult to make valid comparisons with other studies without more information. Indeed, the development of a widely accepted protocol for doing these kinds of experiments would greatly facilitate comparison and interpretation of results. First, it would be helpful to know more about the specific cultural techniques and irrigation practices used by the organic and conventional growers. Could it be possible that other cultural techniques used in organic agriculture, aside from fertilization methods, are responsible for some or all of the nutritional differences? Did all of the organic growers use the same techniques? It would have been interesting to see more specific data on the nutrient contents of the vegetables by farm to examine whether particular farms yielded consistently different results. Information on the conventional growers' cultural techniques, use of pesticides and other petrochemical inputs is also lacking. Second, we do not have information on how long each of the organic growers had been practicing organically. This time factor could affect the soil quality and potentially, the nutritional quality of the vegetables.

Finally, despite the interest this type of study attracts, it is important to bear in mind that the differences between organic and conventional produce must be considered within a broad context. Although consistent differences in specific nutrients may eventually be found, their contribution to overall health is questionable, given most North Americans' and Europeans' access to food. Choosing organically grown produce for its contribution to the long-term health of the soil and our capacity to produce food sustainably may ultimately be more important than its contribution to individual nutritional health.

For more information write to: Unite de Toxiologie Nutritionnelle, Station de Recherches sur la Qualite des Aliments de l'Homme, I.N.R.A., 17 rue Sully, F-21034 Dijon-Cedex, France.

(GWF.OO7) *Contributed by Gail Feenstra*

Winter 1992 (v3n1)

Understory cover crops in pecan orchards: Possible management systems.

Bugg, Robert L., Marianne Sarrantonio, James D. Dutcher and Sharad C. Phatak

American J. Alternative Agriculture 6(2):50-62. 1991

Reviewer's Note: This conceptual and review article concerns possible cover-cropping approaches for the pecan orchards of southern Georgia. Many of the cover crops discussed in this article also grow well in parts of California, and several of the suggested techniques may be adaptable to pecan a6d walnut production in this state.

Annual legumes and mixtures of annual legumes and grasses can perform several functions as understory cover crops in pecan orchards, such as providing nitrogen-rich organic matter to improve soil fertility, or by sustaining lady beetles and other arthropods that may aid the biological control of pecan pests. Remaining questions concern selection of appropriate plant materials; whether to use cover crops singly or in mixtures; how to ensure reseeding as well as a substantial N contribution; whether, when, and how to use mowing and tillage; and fertilization options.

Different considerations apply when dealing with cool -vs. warm-season cover crops. With minor adjustments, growers could adapt present cultural practices to include cool-season cover crops. These could be used throughout the orchard by establishing appropriate self-reseeding species and avoiding both excessive mowing and indiscriminate placement of N-rich fertilizers. Within alleys, alternating 2-m strips of cool-season cover crops could be tilled in mid to late April or allowed to mature. The tilled strips would supply N to pecan trees immediately, whereas the adjoining untilled (remnant) strips could be mowed after seed is mature, to ensure dispersal of seed and reestablishment of cover crops over the entire alley. Cool-season annual legumes that die or are killed in late spring will probably furnish N and other nutrients at a suitable time, particularly in orchards with sprinkler irrigation. Soil moisture is essential to the breakdown of cover crop residue and the release of N to the associated pecan trees.

Warm-season cover crops, if desired, should be restricted to alleys to reduce possible competition with pecan. Cover crops in alleys will receive more light than in tree rows, especially during periods when pecan trees are in leaf. Tillage will encourage emergence of warm-season cover crops. If these die or are killed in late summer or early fall, timing of N release may not be optimal, particularly in the absence of adequate irrigation.

Many options and trade-offs need to be explored before choosing a cover-crop system. At times, several objectives may appear to conflict, and even delicately-managed mixtures of species may not fulfill all the desired functions.

For more information write to: Information Group, UC Sustainable Agriculture Research and Education Program, University of California, Davis, CA 9S616.

(DEC.330) *Contributed by Robert Bugg*

Cool-season cover crops relay intercropped with cantaloupe: Influence on a generalist predator *Geocoris punctipes* (Hemiptera: Lygaeidae).

Bugg, Robert L., Felix L. Wackers, Kathryn E. Brunson, James D. Dutcher and Sharad C. Phatak

J. Economic Entomology 84:408-416. 1991

*Reviewer's Note: Several species of bigeyed bugs (***Geocoris** *spp.) are important generalist predators in California field and row crops; these bugs attack a wide array of pests and are believed important in preventing outbreaks of aphids and various species of Lepidoptera.* **Geocoris punctipes***, the subject of this paper, is abundant in much of California, Arizona, and the southeastern U.S. If, as this study suggests, cover crops can be used to improve performance of these and other generalist predators, this could have important implications for pest management.*

In southern Georgia, fall-seeded cool-season cover crops were used in efforts to enhance densities of entomophagous insects on relay-intercropped spring plantings of cantaloupe. Eight cover-cropping regimes, including 'Mt. Barker' subterranean clover (*Trifolium subterraneum*) 'Vantage' vetch (*Vicia sativa* X *Vicia cordata*), 'Chilean 78' common lentil (*Lens culinaris*), 'Dixie' crimson clover (*Trifolium incarnatum*), 'Wrens Abruzzi' cereal rye (*Secale cereale*), 'Florida Broadleaf' mustard (*Brassica hirta*), a six-way polyculture of the crops just mentioned (which was dominated by cereal rye), and a weedy fallow control, were tested in a replicated trial. Cover crop significantly affected densities of the predominant predator, a bigeyed bug, *Geocoris punctipes*, amid cover crops (P=0.000l); on or near cantaloupe plants (P= 0.0001); and on or near sentinel egg masses of fall armyworm, *Spodoptera frugiperda* pinned to cantaloupe leaves (P=0.0487). Thirteen types of predatory arthropod were found feeding on these egg masses. No significant difference was found for proportions of egg masses occupied or damaged by predators, but this non-significance was marginal (P = 0.0637). For all measurements of predator abundance and efficiency, absolute responses were highest for the plots of subterranean clover. Numbers of bigeyed bugs per sentinel egg mass were significantly greater for the subterranean clover regime than for cereal rye, crimson clover, and a polyculture of six cover crops, but were not significantly greater than for 'Vantage' vetch or the weedy fallow control plots. Rye showed particularly low densities of bigeyed bugs. Cover crops had no apparent effect on densities of aphids or whiteflies on cantaloupe leaves, but densities of these pests were uniformly low through-out the study.

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(DEC.331) *Contributed by Robert Bugg*

Predatory and parasitic wasps (Hymenoptera) feeding at flowers of sweet fennel (*Foeniculum vulgare* Miller var. *dulce* Battandier & Trabut, Apiaceae) and spearmint (*Mentha spicata* L., Lamiaceae) in Massachusetts.

Maingay, Hilde M., Robert L. Bugg, Robert W Carlson, and Nita A. Davidson

Biological Agriculture and Horticulture 7:363-383. 1991

Reviewer's note: Parasitic wasps are important in the biological control of various insect pests. Adult wasps are often reliant on nectar. Sweet fennel is a common roadside weed in much of California so this study, conducted in Massachusetts, may find application here.

Sweet fennel (*Foeniculum vulgare* Miller var. *dulce*) and spearmint (*Mentha spicata*) grew and flowered in 0.5 X 1 .0-m, plots located amid an organic market garden (Site 1). During 1985, 12 approximately-weekly sets of aerialnet collections were made from August 7th through October 22nd from single experimental plots planted to each of the two species. On each date, samples were taken during three-minute episodes at hourly intervals from 0830-1630 EDST. Additional nearby plantings of sweet fennel in an herb garden (Site 2) were used for occasional supplemental sampling of flower visitors.

Sweet fennel flowered throughout the 12 weeks of sampling. Four hundred and ninety-seven insect specimens were collected from a small plot of sweet fennel occurring in Site 1, with 195 representing taxa that are at least in part predatory, and 105 representing groups that are at least partially parasitic. Wasps (Hymenoptera) collected from sweet fennel at Sites 1 and 2 included four species of Sphecidae and four of Vespidae (including yellowjackets and paper wasps). Eighty-seven specimens of Ichneumonidae were collected, representing 48 distinguishable species and eight subfamilies. In addition, 11 adult Coccinellidae, representing five species, were observed feeding at sweet fennel flowers. Spearmint flowered from about August 21st until September 25th, during which time 277 insect specimens were collected, including 53 from mainly-predatory taxa and 33 representing principally-parasitic groups. Wasps included six species of Sphecidae, two of Eumenidae, two of Vespidae, and two of Ichneumonidae.

Few Ichneumonidae occurred at Site 1 before August 21st; peaks of attendance occurred on September 25th and October 16th. Vespidae showed highest visitation rates on August 28th. Sphecidae were most abundant on September 3rd. Peak attendances by ichneumonids and vespids were at 0900 hours, followed by apparent reduced foraging during midmorning, and relatively high visitation rates from late morning through early afternoon. Sphecidae peaked during late morning, was lower during early afternoon, recovered somewhat during mid afternoon, and again dropped during late afternoon.

Flowering herbs such as sweet fennel and spearmint are often grown in close proximity to vegetable crops on diversified organic truck farms and in community gardens. Of the ichneumonid species collected, eight are known parasites of significant agricultural pests. Several of the predatory wasps observed also attack pests. Future studies could determine whether these or other flowering herbs could contribute to enhanced biological control of insect pests.

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(DEC.332) *Contributed by Robert Bugg*

Causes and consequences of overfertilization in orchards.

Weinbaum, S.A., R. S. Johnson, and TM. DeJong

J. Horticultural Technology 1(2): in press. 1992

Reviewer's note: Nitrogen is the element most often applied in orchards to enhance tree growth and production. For most fruit crops, increasing N rates above an optimal level often results in increased yields, but also deterioration of fruit quality. Conversely, yields in other tree crops (especially nut crops) may increase with little or no reduction in quality. There is a point of diminishing returns, however, beyond which the income received for the product does not cover the cost of the extra fertilizer. More importantly, the extra N applied before this point is reached can represent an environmental cost in terms of nitrate contamination of groundwater. The effect on groundwater is the primary focus in this extensive review paper (115 references).

Overfertilization with N is defined as "the application of N in excess of the tree/vine capacity to utilize it for optimum productivity." This practice can lead to a buildup of N in the soil, where it becomes vulnerable to loss by denitrification (which produces volatile nitrogen gases) and leaching. Tree and vine crops may be more susceptible to such losses than other crops. In one San Joaquin Valley study, the proportion of applied N that was removed in harvested crops was found to be substantially lower for tree crops than for other crops (Table 1). A study in Fresno County showed that more Soil nitrate accumulated below the root zones of orchard crops than at similar depths in other crop classes.

Table 1. Estimated fertilizer and residual soil N use and removal by crops in the San Joaquin Valley (1961 vs. 1971).

Crop	1961	1971	N Applied		N removed in harvested crop		Percent removal a/	
			1961	1971	1961	1971	1961	1971
	- acres-		-lbs/ac-		-short tons-			
Field	1,587,370	1,602,196	104	107	47,276	45,935	57	54
Hay	234,992	228,073	51	94	7,604	7,824	100	73
Vegetable	127,009	141,588	134	161	4,408	4,959	52	43
Tree	161,603	284,412	102	109	1,433	2,865	17	19
Vine	260,938	287,130	34	44	1,653	2,314	37	37
Total	2,371,66	2,543,400			62,373	63,916		

a/ Percentage based on amount of N applied and that removed in harvested crops. N contents of the edible portion of the crops were obtained by laboratory analyses and local sources.

Source: Miller and Smith, 1976.

Fruit Tree Response to Overfertilization

Overfertilization is associated with a number of adverse consequences in orchards in addition to its negative impacts on the environment. First, excess N can result in increased vegetative growth which "accentuates shading within the tree and negatively affects flower bud development, fruit set, fruit quality, and shoot survival." Second, overfertilization in stone fruits delays fruit maturity and can lead to uneven ripening of fruit on a tree and on individual fruits. Third, high N inhibits proper fruit coloration in many species. Finally, several physiological disorders may be accentuated by overfertilization; susceptibility to disease and insect pests may be influenced as well.

Factors Contributing to Overfertilization

The authors describe three factors which must be more fully understood in order to prevent overfertilization: 1) the efficiency of fertilizer N use, 2) other sources of plant- available N, and 3) the tree requirements for N (demand).

Fertilizer N Use Efficiency (NUE) is the proportion of fertilizer N recovered by the plant relative to the total amount of fertilizer N applied. The NUE for most California fruit growers is currently less than 25 percent, i.e. they apply more than four times the amount of N recovered from the land in the plant. Such a low NUE results in increased losses, including leaching to groundwater. Overwatering increases nitrate leaching (especially in coarse-textured soils), which encourages the grower to apply high rates of fertilizer N. Thus, prevention of nitrate pollution requires not only reducing N rates, but also minimizing deep percolation. To reduce deep percolation, careful monitoring of soil moisture and knowledge of evapotranspiration rates are essential. Reducing fertilization rates increases the percentage recovery of N by trees and reduces the potential for leaching of residual fertilizer N. Other practices that can increase NUE and reduce nitrate leaching include split fertilizer applications, low-volume irrigation and fertigation.

An important factor affecting NUE is the timing of N fertilization. Winter applications were used in the days of dryland farming to carry N into the root zone. Fertilization took place in the winter because of the increased availability of labor and because it was believed that this N would be readily available for uptake by trees in early spring. However, extensive research has shown that N used in the early spring growth of trees comes from uptake from the soil prior to leaf fall. This N is stored in perennial tissues over the winter and is translocated to developing blossoms during the early stages of growth resumption in spring. Because little N is taken up from the soil until the period of rapid shoot growth in the spring, winter-applied N is vulnerable to leaching.

NUE may also be affected by alternate bearing (alternating heavy and light crops each year). During a heavy production year, root growth is limited; consequently, the capacity for N uptake can be reduced. *(Reviewer's note: More N is removed in the crop in a heavy crop season than in a light production year. However, the evidence indicates that the ability of the tree to take up N from the soil is reduced when a heavy crop is present. Thus, high N rates applied during a heavy crop year, in anticipation of excess N removal, may be wasteful and polluting. Implications for N management strategies in light of these phenomena are currently under investigation.)*

Plant-Available N is the chemical form of soil N (mostly nitrate) that can be absorbed readily by plant roots. Plant- available N makes up less than 3 percent of the total soil N; the rest is immobilized in the soil organic matter and is available only as organic matter de-composes. In some cases, there may be sufficient plant-available N from non-fertilizer sources to maintain tree productivity for extended periods (i.e., 4-6 years). For example, N in organic matter (some of which may be from previous fertilizer applications) can mineralize and become available.

Irrigation water is another source of nitrate-N. Nitrate in well water has increased in many parts of California. In the San Joaquin Valley, such irrigation water commonly supplies 70-100 kg N per hectare (approx. 60-90 lbs. per acre) each year to tree crops. Thus, in order to reduce groundwater contamination, it is recommended to consider irrigation water as a N source and to adjust fertilizer rates accordingly. In some cases, sufficient N is present in the irrigation water to satisfy the N requirements of the crop without further N supplementation. [See Hirschfelt, *Components* 1(3), 1990.]

Tree N Utilization (Demand). Proper N fertilization requires that you know the amount of N removed by a crop in a season. As shown in table 2, this figure can differ by as much as 1000 percent between species. The N contained in other plant parts, such as leaves and prunings, is insignificant compared to that removed in the crop. With almonds and walnuts, for example, only 4-8 lbs. N per acre are removed in prunings. A program of N fertilization based solely on crop removal, however, may not lead to optimum production since other environmental and management factors influence NUE.

N uptake and tree response can decrease progressively with incremental increases in N application rates. This decrease may indicate luxury consumption of N; more often, however, the capacity of plants to take up N decreases as maximum productivity and vegetative growth occur. The decline in N uptake leads to excess accumulation of nitrate in the soil which can move with percolating water to groundwater.

Table 2. Estimates of crop nitrogen removal in major California tree crops.

Species	N Removed per ton of crop a/ (lbs/ton)	N Removed in crop b/ (lbs/acre)
Almond (Nonpareil)	70.60 c/	54-8
Apple (Gold. Del.)	1.00	20-29
Apricot (Tilton)	5.00	49-76
Cherry (Bing)	2.70	13-20
Grapes (avg.)	2.90	29-45
Kiwifruit (Hayward)	3.60	36-54
Nectarine (R. Giant)	1.94	29-48
Orange (Navel)	4.20	53-73
Pistachio (Kerman)	52.40 /d	79-131
Peach, Cling (Halford)	2.14	43-64
Peach, Free (O'Henry)	2.56	38-64
Pear (Bartlett)	1.30	26-38
Plum (Simka)	2.84	28-43

Prune (Imp. French)	3.70	45-66
Walnut (Chico)	35.80 d/	71-107

a/ All estimates except for oranges and grapes are based on tissue analysis of all parts of fruit harvested under semi- commercial conditions in the Pomology Dept. orchards at UC Davis or the UC Kearney Ag. Center near Fresno, CA. Data for oranges and grapes are adapted from Birdsall et al., 1961 and Mullins et al., 1992, respectively. All values are for fresh fruit except for the nut crops.

b/ Based on a range of yields, considered very good to excellent under California conditions. Yield figures (short tons/acre) are obtainable by dividing N removed in crop (lbs./acre) by N removed per ton of crop (lbs./ton).

c/ Based on kernel weight with standard 5 % moisture content.

d/ Based on in-shell weight with standard 8% moisture content.

Diagnosis as a Guide to Fertilization

This section begins with an analysis of grower motivations behind the selection of fertilization practices. It is not possible to accurately predict N requirements for optimum productivity over a diversity of sites. Nonetheless, diagnostic possibilities and relevant information exist to keep N losses to a minimum; yet most growers are inclined to ignore these resources. Management practices are often based on tradition (e.g., winter fertilization), testimonials (e.g., perceived cause and effect relationships of neighboring farmers), and convenience (e.g., uniform fertilization of a field with two soil types). A sound approach to N fertilization involves the diagnosis of tree N status and soil N availability, knowledge of crop N demand, and consideration of other site-specific variables.

Diagnostic methods for determining N requirements include tissue testing and soil testing. Soil tests can reveal the need for less N fertilizer if high levels of residual nitrate are detected. In general, however, soil tests do not account for the spatial variability in soil nitrate concentrations, root distribution, and soil N mineralization potential. Also, even if soil N levels are low, tree N reserves may be used to produce an adequate crop in a given year.

Tissue tests are more indicative of N availability than soil tests. In orchards, the total N concentration (percent dry weight) is determined from leaves sampled in mid-summer. Leaf analysis in citrus is largely responsible for a 50 percent reduction in N fertilization rates in orange groves in some areas of California. However, an informal survey indicated that less than 20 percent of tree fruit growers statewide perform leaf analysis annually. Furthermore, variability exists among laboratories and advisers in the accuracy of results, the basis of interpretation, and the ensuing recommendations. It is also noted that commercial crop advisers often have a vested interest in selling fertilizers.

If tree N status is initially low, leaf N concentrations increase significantly with the application of fertilizer N. However, leaf analysis results are relatively insensitive to *excessive* N fertilization rates. In one study, doubling the N application rate to apples failed to increase leaf N significantly. High leaf N levels (i.e., above the sufficiency threshold) usually indicate overfertilization and thus an increased potential for leaching and volatilization of N. Yet little research has been carried out to address the upper limit of the N sufficiency range.

According to the authors, the goal of maximizing economic profitability has led to environmental degradation. The high ratio of fruit value to fertilizer cost has encouraged overfertilization. They predict that the price of fertilizer would have to increase by more than 200 percent before growers will use fertilizers judiciously. While many practices have been recommended to minimize N losses, it will take legislative action to produce the desired results unless all participants take a more proactive approach.

Reviewer Comments

From a political perspective, regulations restricting N fertilizer usage will almost certainly be enacted if nitrate levels in groundwater continue to rise. Will growers wait until they are forced to change? The answer is likely to be yes, particularly if fertilizers remain relatively cheap. Many growers are concerned about groundwater contamination. Yet it is difficult to risk reductions in yield, especially when the difference between profit and loss may be just an extra shot of fertilizer away. The question of responsibility further complicates the problem. There are many sources of nitrate contamination and each grower's contribution is usually small. For these reasons, it seems likely that growers will need strong economic incentives or regulations to persuade them to maximize the efficiency of N fertilizer use.

One practice not mentioned in the article that has potential for reducing nitrate pollution is the use of cover crops, including resident vegetation. Nitrate leaching potential is usually greatest during the winter, when N uptake by tree roots is low and rainfall is highest. Winter cover crops (especially nonlegumes) can capture much of the nitrate that would otherwise leach. Since the amount of soil residual nitrate captured by a cover crop is proportional to the plant biomass, the cover must have significant biomass by early winter in order to be effective. Cultivating or mowing the cover would be appropriate in early spring, particularly during drought periods.

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