METHODOLOGY

Demonstrating the Gap

The identification and documentation of the gaps in knowledge of soil science and the problems associated with improper fertilization were accomplished from several perspectives: California Department of Food and Agriculture (CDFA) fertilizer sales figures, a dealer survey, literature review, and compilation of soil analysis data.

The annual sales of fertilizers and amendments grouped by county are available from the CDFA. I obtained the appropriate records, and prepared a report on the data showing trends in fertilizer use in the study area for the period 1975-1995. This demonstrates the actual fertilizers used in agriculture.

I conducted a survey to determine the educational levels of those in the local fertilizer industry who are in regular contact with customers. This uncovered training needs and provided industry's perceptions of the fertilizers used and the nature of our soils.

I reviewed the literature on local crop needs and summarized the fertilizers recommended to show what university, private laboratory and industry sources advise. I compared this to the actual practices (from CDFA fertilizer sales) and the perceived crop needs (from the dealer survey). Significant differences are evidence for the need for a training program.

I tabulated information and data from my soil testing the last 20 years, and grouped local soils according to Albrecht's system. I used tests from other dealers and the local laboratory in Ukiah to add to my 2,000 tests from the study area. I selected about 500 of these analyses to reflect soils that are either close to "native" condition or have been farmed according to the prevalent practices in the area. These soil groups are presented in a form that follows the United

States Department of Agriculture (USDA) Natural Resource Conservation Service soil surveys. Soil nutritional information was added to the present USDA soil surveys that will be extremely valuable in managing crops and soils. The resulting system for categorizing soils can be adapted and used anywhere in the world.

I developed a model, using Albrecht's approach, my personal experience, and the literature review. The results of the dealer survey and fertilizer sales trends helped provide direction. The educational program using this model presents information utilizing color graphics, charts and illustrations along with text to provide accurate practical methods for fertility analysis and applied fertilization practices. Based on my experience, a community college level program is appropriate for industry use.

Fertilizer Dealer Survey

From the CDFA Fertilizing Materials Licensee List (1996), I compiled the names, addresses and phone numbers of dealers in the five county area. I formulated a data base of all 56 registered dealers, and sent a mailer describing the project and introducing myself as a graduate student doing a research project on the fertilizer industry.

The phone survey narrowed the dealers down to 40 actively dealing with the farm and horticulture industries in a 5 county area. I directed questions to and about the people in contact with the customers: sales people, fieldmen, advisors, consultants, and counter people - anyone who makes substantial contact with customers regarding fertilizer purchases and use.

CDFA Fertilizer Sales Records.

Records of fertilizer use for the last 20 years were researched and duplicated from records of the California Department of Food and Agriculture

(CDFA, 1975-1995) office in Sacramento. Two categories of annual tonnage reports were used: Fertilizer (materials with 5%+ N, P and/or K) and Agricultural Minerals (secondary nutrients & miscellaneous.).

I entered the fertilizer sales into a spreadsheet, grouped by county, so that fertilizer amounts & types by year could be used to figure percentage and total sales of each fertilizer or agricultural mineral. The figures were then added to another spreadsheet to show total annual sales of N, P, K , and calcium amendments for the northern counties of Contra Costa, Lake, Mendocino, Napa, and Sonoma.

Soil Classification System

The USDA Natural Resource Conservation Service (USDA-NRCS), in cooperation with other federal, state, and local agencies, conducted soil surveys throughout the U.S. These surveys are intended for use by farmers, ranchers, and foresters to evaluate potential uses of the soil and management practices needed for production. Planners, engineers, developers and builders can use the information to plan land use and modifications. Soils were observed and grouped according to slope, color, kinds of crops and native vegetation. Sampling and analysis of the different soil profiles for color, texture, aggregates and reaction were performed, and the soils assigned to taxonomic classes with defined characteristics. Unfortunately, because most of the tests were done in the field, little specific nutritional information was gathered.

Albrecht's system of soil testing and classification was formulated with soil biological productivity in mind. I have expanded on this in the literature review. Selecting soil data from over 2,000 analyses, I created a classification system that will overlay the USDA-NRS soil survey maps, filling in important gaps in the knowledge of soils in the study area. This is a simple system of classifying general soil groups by major nutritional characteristics.

Soil Analysis Interpretation Model

The production of a concise, practical model for soil analysis interpretation and fertilizer recommendation is the ultimate goal of this project. The audience for such a publication, those involved in fertilizer sales, consulting, or farm management are people already well versed in the basics of soil science. Soil engineers and technicians will find the information broadens their expertise with usable knowledge.

Numerous books, journals and studies on almost every aspect of this very technical subject are available - yet common sense, and applied scientific applications of soil science are often lacking. This project will both document and help fill this important gap in technical knowledge. The model is a product of material from the literature review and my own personal experience. I have included examples and exercises to help the reader learn to use the information. Emphasis is on simplicity, clarity, practicality and accuracy. Color graphics and charts enhance its utility.

LITERATURE REVIEW

In the literature review I provide an overview of the problems associated with fertilizer management, the theoretical approach I am recommending to deal with the problems, and progress which is taking place towards that end. Two main philosophies of soil analysis interpretation will be critically examined, from the literature and my personal experience.

Problems with groundwater pollution, persistent and often increased pest & disease pressure, and reductions in yield or quality have created the need for truly integrated management systems in production agriculture. Critical components in such systems are soil analysis and fertility management. I have reviewed the historical evolution of approaches to soil analysis interpretation, provided a usable system, and shown specific applications in northern California agriculture which address these problems.

Over Fertilization and Pollution

Nitrogen (N) is considered the most critical management input, besides water, for tree fruit production. Yet applications of N fertilizers are not always efficient; the percentage of applied N which is removed from the field in the crop is lowest in fruit trees (<20%), followed by grapes (37%), vegetables (55%) and hay (>70%) (Sanchez, Khemira, Sugar, & Righetti, 1996). Tree fruits and vines thus have a high potential for environmental pollution. Nitrogen leaching into groundwater is becoming a problem in many areas of California. Embleton et al. (1986) studied N fertilization in California citrus orchards. They found that lower rates of soil applied N could be combined with foliar sprays to reduce total amounts and subsequent pollution. The study did not address specific soil conditions for best nitrogen uptake.

Ingels and Miller (1993) addressed the soil N pollution issue in California, emphasizing orchards, and citing the importance of cover crops in nitrogen management. They mentioned the need for more knowledge: "Many practices aimed at improving nitrogen-use efficiency have been developed, although many gaps in information still exist." They claim that over fertilization in tree crops is still common because most growers rely on synthetic fertilizers. This project will help fill the gaps in using fertilizers efficiently.

Yield and Quality Considerations

Farmers are in business to raise a crop; success is measured in tons, bushels, boxes or other standard measure of yield. Prices and yields are matched against total and per acre costs to determine profits, success and longevity of the business. If yield alone is the main criterion, farmers can use large rates of N fertilizers and get away with ignoring more complex aspects of soil fertility .

Quality considerations are often minimum standards of crude protein for grains and feeds, and cosmetic considerations for fruits and vegetables. Flavor and nutritional makeup are rarely considered. The main quality criteria for tree fruits and vines are usually minimum sugar contents and grading sizes. Premium wine grapes, where superior flavor is desired, are exceptions, as are apples or pears which are stored for long periods to supply off season fruit.

Years of research in the apple and pear industry resulted in the ability to store fruit for over 8 months in controlled-atmosphere facilities; proper nutrition of the orchards is essential to that end. Rom (1994, p. 17) warned "mismanagement of a small, atomic element present in only part-per-million concentrations in fruit trees can have disastrous economic consequences." Careful management of nitrogen, attention to the ratios of calcium, magnesium, & potassium, and the level of micronutrients are all used to insure fruit going into cold storage has the best chances of remaining firm and salable. Soil amendments, foliar sprays and nutrient dips of harvested fruit are all used to insure optimum nutrition.

Earlier, I mentioned the emphasis winemakers place on the flavor of grapes in producing quality wines. A generalized, systematic model for interpreting soil analysis results would help producers make decisions on fertilization practices which affect quality of fruit. Growers and processors, given more information, could concentrate on flavor and other more subtle considerations.

Pest and Disease Management

The term Integrated Pest Management (IPM) gained popularity slowly in the early 70's as many problems from pesticide use in the 1960's became evident. Environmental pollution, pest resistance, and rising costs of insect and disease control resulted in the formation of government programs to elevate pest control to a science. I worked in the California Pear Pest Management program from 1973-1975, and since have worked in the private development of IPM programs for apples, grapes, peaches, and greenhouse crops. In IPM "factors such as prior pest history, crop growth and development, weather, visual observations, pest monitoring information, and cultural practices [are] considered before control decisions are made" (Marer, Flint, & Stimmann, 1988, p. 67). Fertilization is considered one of many cultural practices, including pruning, planting, ground preparation, and irrigation. Manuals designed for use by growers and practitioners of IPM have extensive information on pests & diseases, life cycles, counting and evaluating populations, and control measures - yet links between fertilization and pests are not commonly made. A comparison of the management of a major crop disease and its relationship to soil fertility, using guidelines from two versions of IPM manuals, shows that some progress is being made in using a truly integrated outlook.

In practice, growers often apply excess nitrogen to the exclusion of other nutrients- then spray pesticides to fight problems that are due partly to nutritional imbalances. Fireblight, a bacterial disease, is one of the most devastating problems pear growers face world wide. In Pear Pest Management, Bethell (1978, p. 165) wrote: "fireblight management still places heavy reliance on spring blossom sprays." The management guidelines in this manual did not say anything about soil fertility. A newer book, IPM for Apples & Pears (1991), gives clear warnings on the effects of excess nitrogen on both fireblight and psylla (a serious insect pest). The authors give generic guidelines for proper fertilization, though no technical information for dealing with specific soil types are shown. Similar trends show up in other crop production manuals; relationships between pests & diseases and fertilization are not addressed if they are not obvious.

In a research report on "Integrated Control of Botrytis Bunch Rot of Grape" (Bettiga, Gubler, Marois, Bledsole, 1989), a disease common to coastal grapes, the authors advocated using fewer pesticides with such cultural practices as pruning and training to open vine canopies. These cultural practices were shown to decrease disease susceptibility. Yet no soil nutrient interactions are addressed - although I will show later several studies indicating such interactions. This is a recurring problem in research and practice - all the major influences on pests & diseases are not considered - even in so-called "integrated" programs.

Most textbooks on soil science and plant nutrition mention, and some stress, the importance of proper fertilization and soil fertility management for producing healthy crops. However fertilization practices are often ignored in pest and disease management and research. Studies of soils and plant nutrition, plant pathology and entomology are traditionally performed separately. Yet when the principles of soil science are applied to the fertilization program, many pest and disease problems diminish. Soils & fertilization, insect and mite pests, and plant diseases are studied under separate disciplines, with different departments in most universities. Evidence increasingly points to the conclusion that merging the disciplines of soil science, plant nutrition and pest management is necessary for modern production.

Which nutrients affect pest and disease problems? They all do to some extent. "All of the essential mineral elements are reported to influence disease incidence or severity" (Huber, 1989, p. 2). Nutrients are one of the four main factors involved in plant disease; the others are microbes, host plants, and the growing environment. Insect and other pests which consume plant parts are more obviously involved: their growth and reproduction depends on their food supply. More often than not, nitrogen, the most commonly applied nutrient, is involved. According to Denno (1985, p. 159), "In summary, increased plant nitrogen can have considerable effect on performance of phytophagous insects, resulting in improved individual fitness and a larger population outbreak." In other words, over reliance on N fertilizers actually makes the plants weaker and the insects stronger. Clearly, attention to levels of nutrients is important in resistance to pests.

Truly Integrated Management Systems for Agriculture

Applied research projects between farmers, consultants, and researchers are being formed to promote whole systems approaches to agriculture. Projects such as Biologically Integrated Farming Systems (BIFS), Biologically Integrated Orchard Systems (BIOS) and Biological Prune Systems (BPS) are undertaken to investigate "integration of biological soil building and pest management systems, cover crops, composting, beneficial insects, vegetative filter strips, border plantings... and other optional practices ..." (Burnham, 1997, p. 5). Among the goals of the programs are reduced pesticide and synthetic nitrogen use along with best production.

Calls for truly integrated programs are not new; William Albrecht was one of the pioneers in actually researching fertility, pest and disease relations. His approach was well summarized in an article he wrote for the Journal of Applied Nutrition in 1970 (p. 31):

> If we are to solve the insect and disease problems most wisely for the plants, animals, and ourselves, it is not going to be by a call on only the insecticides and the drugs. Rather it will be by also rebuilding our soils in their fertility.

That was not a time when the notion of reduced pesticide use was popular among farmers and agronomists. Few others were applying sophisticated farm management systems with that goal. Since then, many others have called for truly integrated or holistic systems for approaching various problems in crops: Dundon, Smart & McCarthy (1984) in grapes; Young (1988) in orchards and vineyards; and Sugar, Righetti, Sanchez and Khemira (1992) in orchards.

The use of soil, leaf and tissue analysis in fertilizer and nutrition diagnosis and evaluation has a long history. With the development of more sophisticated analytical instruments in the 1920-1930s, fertility analysis and research grew to its present state with private, government and university labs world wide adopting and cross-referencing methods and results. Many standardized methods for analysis now exist - yet interpretations can be very subjective. Often agronomists who manage laboratories and perform analyses make fertilizer recommendations for crops and soils hundreds of miles away. Carl Spiva, agronomist with A & L Western Agricultural Laboratories (personal communication, 1984) proposed that ideally, local practitioners should prescribe and recommend fertilizers, working closely with the growers and crops in their area. The absence of universal, systematic methods of soil analysis interpretation, applied to local conditions, is a limiting factor in the development of truly integrated programs.

I developed the following principles through my own experience and that of others during the period 1973-1987. Since then, I have applied this system to tree fruits, vineyards, and vegetables in northern California with the specific objectives of optimum yield, crop quality, and pest and disease resistance. Based on Albrecht's principles, it is a practical, workable system which could be applied and fine tuned in medium to high rainfall regions anywhere.

Table 1

Basic Principles of Soil Balancing and Optimum Fertilization

1. Balance soil exchangeable cations to: 65-75% Ca; 10-15% Mg; 2-5% K; 0-5% Na (as % of total cation exchange capacity; maintaining cation balance with appropriate mineral amendments
2. Maintain P, K, S and micronutrients at generous levels.
3. Build and maintain organic matter through cover cropping, addition of composted organic matter and/or microbial soil inoculants, and promotion of healthy biological activity in soil.
4. Supply nitrogen in adequate amounts (for crop needs *only*), avoiding excess soluble N, applying N sparingly in split applications or via composted organic matter for activation of N cycle and slow release.
5. Use foliar feeding to supply nutrients known to be deficient; applying during stressful times (bloom. maturity, adverse weather, pest/disease pressure, etc.

From Young (1988).

Each principle will be discussed in general, with supporting research, and in specific applications in northern California.