8 Improving Crop Management and Farm Profitability: New Approaches for Advisory Services[1]

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Farmers are under severe economic pressure. Their production costs have tended to inflate while commodity prices have decreased. Current farm management emphasizes increased input efficiency. Optimum balance of plant nutrients is essential for obtaining high economic yields. Soil testing and plant analysis are our best sources of information for making accurate fertilizer recommendations. Accurate fertilizer recommendations aid farmers in achieving the required nutrient balance without over- or under investing in fertilizer.

University and federal research agencies have traditionally provided the methodologies and correlation data used in soil testing. Many commercial soil-testing laboratories have adapted methodologies recommended by universities in each state or geographic region. Analytical results from different soil-testing laboratories are often comparable, but fertilizer recommendations among the same laboratories may vary drastically (Olson et al., 1982). This large variation in fertilizer recommendations is causing farmers to become skeptical about the value of soil testing. There is an urgent need to re-establish credibility by standardizing fertilizer recommendations as much as possible. Recommendation uniformity will be improved when all crop-production factors that affect yield potential are considered. Use of crop-production computer models adapted to a given geographic region by crop advisors will help accomplish this goal. This will assure that sufficient but not excessive fertilizer is recommended to meet the yield potential of individual fields, which is influenced by a number of crop management factors.

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CROP MANAGEMENT FACTORS AND THE COMPUTER AGE

The term *crop management* includes a critical group of production factors. Some of the vital crop management inputs are (i) rates of fertilizer and lime; (ii) pesticide applications; (iii) planting date and method; (iv) variety selection; (v) plant population; (vi) residue management and seedbed preparation; (vii) soil water status, irrigation needs, and internal drainage; (viii) cultivation; (ix) harvesting methods; (x) crop rotations; and (xi) storage facilities. Some scientists may not consider some of these inputs to be significant, but to the grower and crop consultant all of these factors are vitally important. A systems approach is needed to unify these factors for farmers.

The availability of microcomputers at all levels of farm management (i.e., advisory services to farm homes) has created a real potential for making important management decision-making information more readily available to the end user. Computers can store and retrieve information with ease. Telecommunications makes it possible to access computer programs and data bases stored on mainframe computers located many miles from the user. Weather records are a good example of this capability. Research, extension, and industry personnel are continuing to develop both simple and complex computer models for microcomputers that can aid in making farm-management decisions. Many of these programs will operate on the personal computers used in many farm homes, the Cooperative Extension Service offices, and the agricultural industry.

Advanced soil testing equipment can output test results directly to computers. Incorporating such capabilities together with fertilizer recommendations into an overall data-handling system (a network) will improve the efficiency of laboratory operations. This computer network can store and retrieve current and past information about a field, and can access additional information (for example, precipitation records) and models needed to make a fertilizer recommendation. Such use of computers helps refine and improve the accuracy of fertilizer recommendations as well as increase the efficiency of laboratory operations. Advisory services are encouraged to implement this capability in the immediate future.

Many soil-testing laboratories now use computers for making fertilizer recommendations; however, few consider all of the crop production factors mentioned above in making those recommendations. If they were to do so, in the near future soil-testing laboratories and advisory services could become the users and guardians of the information, programs, and data essential for operating a profitable farm enterprise.

MANAGING SOIL FERTILITY WITHIN CROPPING SYSTEMS

Crops are known to grow satisfactorily for a given climate when supplied with proper amounts of essential plant nutrients. Farmers are using this information to enhance their productivity. In the USA, the Cooperative Extension Service and others have long encouraged and educated farmers to use commercial fertilizer to increase crop production, quality, and profits. This approach assumed, among other things, that maximum yield had top priority since crop prices would far outrun costs. However, the need to educate farmers to fertilize for optimum economic yields is becoming apparent as the cost-price squeeze intensifies and the whole farm economy worsens.

The profitability of fertilizer application is based on yield response. The immediate need of growers is to know how much fertilizer can profitably be applied. Fertilizer application is not always the answer to increasing farm profits. Other factors have to be considered and measured before an optimum economic yield can be predicted. Crop yield on a given soil is influenced by such factors as climate, crop and variety, pest control, cultural practices, soil moisture relationships, rooting depth, fertility level, and physical and chemical conditions of the root zone. Setting a yield goal which considers these factors is often more reliable than just asking the producer's judgment of yield goal. Unrealistic yield goals can result in excessive (or inadequate) fertilization and possibly contribute to environmental pollution.

For example, lack of weed control results in loss of soil-water intended for the crop. This, in turn, results in reduced yield potential and consequently lower fertilizer requirements. Good weed control is essential for optimizing farm profitability.

Seeding date can also influence yield potential. Generally, spring crops respond more favorably to fertilizer applications if the crop is seeded early (Black and Siddoway, 1977; Christensen, 1975). Late seeding may make it necessary to reduce fertilizer recommendations to maintain profitability.

Growing-season precipitation, evapotranspiration demands, and temperature greatly influence crop-yield potential. These factors must be considered when determining yield potential. Yield potential in turn affects the level of plant nutrients required. Dryland crop yields in the Great Plains are directly correlated with plant-available water (soil water and precipitation) (Black and Ford, 1976; Greb, 1983; Halvorson and Kresge, 1982). Therefore, plant-available water must be considered when making crop management decisions and determining yield potential.

Previous crops can have an effect on water use (Black et al., 1981) or soil-water depletion. Use of a monoculture cropping system can result in reduced yields, particularly when a field is cropped every year (Elliott et al., 1978). This problem is not as great where a summer-fallow period is used between crops. Proper crop rotation also helps reduce plant disease and insect infestations and helps break up specific weed pressures. Again, changes in yield potential due to crop rotations will also result in changes in fertilizer nutrient requirements. Stubble management and tillage can also influence the quantity of soil water stored and available for crop growth.

Legume crops reduce the N fertilizer requirement for any nonlegume crop that follows. Most soil-testing laboratories have legume N credits built into their fertilizer recommendation programs. Research has shown a 7 to 12% yield advantage when maize (*Zea mays* L.) or grain sorghum [*Sorghum bicolor* (L.) Moench] follows a legume crop in the rotation (Voss and Shrader, 1979; Classen, 1982). Advisors can show farmers how rotations increase yield potentials, reduce operating expenses, and increase profitability. Application of manure or other organic wastes and removal or return of crop residues can also affect fertilizer (N, P, and K) requirements.

Soil ecologists and microbiologists (Tu and Trevors, 1985; Coleman et al., 1984; Jansson and Persson, 1982) state that soil organisms play a key role in maintaining and improving soil productivity. Organic carbon from soil organic matter, crop residues, and other organic wastes serve as the energy source for these organisms. The soil organisms mineralize nutrients from organic matter and residues into simple forms useable by plants. They also help plants absorb nutrients, as in the case of mycorrhizae. Soils with the right mix of active soil organism populations have a potential to produce higher yields. Soil microflora and their interactions with soil microfauna influence nutrient availability. Soil fungi, bacteria, nematodes, microarthropods, and earthworms all influence the nutrient cycle. Yield potential can be lowered by detrimental soil organisms, including parasitic nematodes and disease-inducing bacteria and fungi, or detrimental mixes of soil organisms. Crop rotation, soil pH, and soil physical properties can be altered to control activity of soil organisms.

Tillage systems may change crop-nutrient requirements. The first year of a no-till or a reduced-tillage system may require greater inputs of fertilizer N relative to inputs for conventional-tillage systems than for later years. Thus, adjustment in fertilizer recommendations may be needed, particularly if the fertilizer is to be broadcast on the soil surface without incorporation. Banding fertilizer below the most biologically active surface-soil layer (>7-cm deep) may reduce the microbial tie-up of any applied N, but may also increase the potential for leaching losses. This practice could therefore reduce the need for a higher rate of fertilizer N in no-till systems during the initial years of using the system (Hoeft and Randall, 1985).

Soil physical and chemical characteristics are major detriments of potential crop yield and fertilizer needs. Soil texture influences the water-holding capacity of a soil and the amount of soil water available for plant growth. A coarse-textured soil has a lower yield potential under dryland conditions than a silt loam soil which has a greater water-holding capacity. Quantity of soil organic matter influences the amount of N mineralized annually from a given soil. Consequently, soil organic matter content can influence the amount of N fertilizer needed to optimize crop yields. The calcium carbonate ($CaCO_3$) or the Fe and Al ion content of a soil will influence the availability of any fertilizer P applied.

Advisory services, with the aid of computers and models, can assist farmers in working through these complex interactions, translating them into practical management recommendations, as more research makes them more understandable. Expert-system computer programs are being built to further advance capabilities to manage these complex interactions.

Kiniry et al. (1983) and Scrivner (1985, personal communication) have developed a computer model that calculates a soil-productivity index based on several soil parameters, measured in 10-cm increments to a depth of 100 cm. These parameters are pH, bulk density, clay concentration, organic matter content, and available soil P and K values. Using such a computer-estimated productivity value, a crop advisor is able to characterize problem fields. This would help the crop advisor and farmer estimate the effect of treatment on productivity and whether costs of improvement can be justified. In some soils, subsoil P and K are positive factors for increasing soil productivity. Thus, fertilizer rates need to be adjusted for all of these factors.

SOIL AND PLANT ANALYSIS IN FERTILITY MANAGEMENT

Soil testing is the best method available to an advisor for making fertilizer recommendations to a grower. Land grant universities have continued fertilizer rate studies over many years. This research has greatly refined fertilizer recommendations. Recently, McLean et al. (1982) have added more sophistication to soil testing. A quick test method was developed to accurately predict the amount of P or K fertilizer a soil requires for optimum yield potential. In the near future, analytical tests like these will be used to predict fixation properties of soils, so that a crop advisor can recommend appropriate fertilizer placement and more accurately suggest "build-up" for each soil type.

Crop advisors or consultants need to use proper soil-sampling techniques and soil test methods adapted and calibrated for a given geographic area. The advisor needs to thoroughly sample soils, including both the surface and subsoil. A sampling depth of 0 to 15 cm is essential for such elements as N, P, K, secondary and micronutrients, and for pH and soil organic matter. In addition, the 15- to 60-cm and 60- to 120-cm depths must be sampled and analyzed for nitrate (NO_3^-) and S to most accurately estimate available soil N and S. With ridge-till, no-till, and other reduced tillage methods, the advisor will have to learn new methods for soil sampling and proper procedures for interpretation of soil analyses. The U.S. Great Plains and the western states have encouraged subsoil sampling for many years. There is currently an interest in deep sampling in the Corn Belt, northeastern, and southeastern areas of the USA. Sampling time will become more important, especially when mobile nutrients are to be measured. Field size is expanding rapidly, and new approaches to sampling are needed.

Advisors need to consider sampling and making fertilizer recommendations based on soil type. Recently, Hest (1985) and Luellen (1985) reported that computer technology has been teamed with a multi-hopper fertilizer spreader for the purpose of adjusting fertilizer application rate to soil type on-the-go. A soils map is made showing the various soil types across the field. The nutrient needs for each soil type, based on soil test results, are input into the computer. The soils map is displayed on a video screen, with the truck's position represented on the screen by the cursor. Fertilizer rates and formulations are changed automatically as the fertilizer applicator moves across the field, encountering the different soil types and nutrient requirements. This same system is capable of herbicide application based on organic matter, pH, a weed map, and other inputs.

Soil test interpretation is one of the most critical steps in making fertilizer recommendations. Interpretation must be based on correlation data researchers supply. An understanding of the sufficiency concept is necessary to understand the responsiveness of a crop under a given set of conditions. University of Nebraska soil test recommendation research (Olson et al., 1982) has shown that the profitability of a fertilizer application is dependent upon the need for the nutrients applied. Their research pointed out several aspects of fertilizer recommendations that are most significant to crop consultants. These are (i) subsoil nutrients contribute to plant growth; (ii) nutrient application in excess of sufficiency levels will not decrease yields; and (iii) environmental, energy, and economic concerns are also involved in fertilizer recommendations.

Plant analysis is another agronomic tool that crop advisors (agronomists) may use to define fertility needs. Plant analysis has traditionally been used as a monitoring tool for measuring nutrient uptake 1 yr for adjustment the next year. Since crop advisors start scouting fields early in the growing season, many fertility problems can be diagnosed early using plant analysis. With plant analysis, the nutrient deficiency can often be diagnosed and treated within 3 or 4 days. The correction of a fertility problem early in the growing season often increases the potential profitability for the growing crop. Proper sampling is crucial for interpretation. Comparison of normal and abnormal samples is often desirable for interpretation.

Adams et al. (1985) developed a computer program for wheat (*Triticum aestivum* L.) plant analysis that monitors the N, P, and K content of wheat plants for the purpose of fertilizer management. The program gives advice to the producer on when to collect plant samples, when to apply fertilizer, and the application rate. The sampling and recommendation process is repeated up to five times during the crop year, depending upon the producer's enrollment date.

NEW TECHNOLOGY FOR SOIL FERTILITY MANAGEMENT

A new profession has developed since 1975 in the farming community. This profession is *crop consulting*. For example, more than 405 000 ha (1 million acres) of Nebraska crop land received crop consulting advice during the 1985 growing season (Lloyd Andersen, 1985, personal communication). A crop consultant gathers pertinent crop production information about a field and then advises the farmer of the management practices to use for maximum economical production. During the growing season, the consultant visits each field on a weekly or semi-weekly basis to scout for pests and in some cases to schedule irrigation. The recommendations for pest control are based on economic thresholds developed by university and commercial research. Irrigation scheduling is usually based on water depletion in the effective root zone and projected evapotranspiration for a selected time period.

Initially, crop consultants developed a program based on integrated pest management (IPM) research. But as the crop consulting business expanded, consultants found that farmers needed as much advice on agronomics as on pest management. Damage that chewing insects caused concerned farmers, but they were not as atuned to observing the more obscure effects of soil compaction, excess fertilization, or nonuniform plant population. Now farmers demand more complete crop management programs. Thus, crop consulting has developed into a reputable profession that is demanding management information from agronomic scientists.

Since crop advisors oversee the complete management of a field, soil and crop scientists must develop a systems approach to crop production that meets their needs. Currently, the agronomic advisor studies the field, visits with the farmer, takes soil and water samples, and checks rooting depth and compaction. He then advises the producer on all aspects of crop production, such as: (i) which variety or hybrid is best suited for the soil and management; (ii) planting rate; (iii) fertilizer rates; (iv) tillage practices (e.g., deep chiseling or residue management); (v) insecticides; (vi) herbicides; (vii) seed treatment; (viii) planting date; (ix) irrigation scheduling; (x) insect control during the growing season; (xi) harvest date and reduction of harvest losses; and (xii) numerous other factors that affect farm profitability.

Crop advisors can help farmers standardize their records so that information can be shared and more easily analyzed. Farmers may want these advisors to keep their records. Farmers need to become more aware of the potential this site-specific information has for improving both yield and profitability.

Doster et al. (1983) suggested that farmers in the Corn Belt might increase net income $25/ha ($10/acre) by selecting and applying fertilizer, seed, chemicals, and tillage according to soil type. To do this, a farmer must be able to (i) determine soil type as he travels across his fields; (ii) switch rates of chemical application on-the-go; (iii) adjust planting and/ or tillage depth on-the-go; and (iv) collect yield and moisture information from the different soil type locations.

As previously noted, technology is becoming available to customize soil management. Computers will soon routinely be used to collect and store data, to recommend various management practices according to soil and crop needs for part of a field, and guide machinery in varying the soil treatment as needed for each part of the field. An inventory of computer software for farmers or farm advisors to use includes more than 700 agricultural extension programs (Strain and Simmons, 1984). In addition, several hundred companies supply commercial software for farmers. Magazines such as *AgriComp* and *Farm Computer News* have arisen to inform computer-owning farmers about these programs.

Several commercial programs are designed to aid soil management decisions, and a number of university and extension soil management programs are available. Some soil fertility programs are included in farm management packages for use on personal computers or in farm program networks, such as AGNET, that are accessible by personal computers. Few programs, however, include field mapping so that farmers can get customized recommendations for different parts of a field based on soil test results from each part. An example is SOIL PLAN (Wisiol et al., 1985), a program developed by USDA-ARS and extension scientists at the University of Illinois.

SOIL PLAN, a microcomputer program, estimates the amounts of N, P, K, and limestone to apply to a field to meet a given yield goal for seven Corn Belt crops. The program allows farmers to get recommendations for P, K, and limestone that are site-specific within a field. Recommendations are based on soil test results and soil type or characteristics, past crops, and crop management plans. If a current soil test is not available, recommendations are adjusted using cropping history and the record of fertilizer use since the last test. Soil type can be selected from a display list of Midwest soils, or soil characteristics can be entered directly if the type is unknown.

SOIL PLAN fertilizer and limestone recommendations are calculated using soil test results, cropping plans, yield goal, soil characteristics, field history, and the quality of the limestone available. If there are results from several soil sampling sites, up to 11 for a field, these values can be entered on a field map on the display screen. The map is easily tailored to fit the shape of the field. The program outlines reasonable groupings of recommended amounts of fertilizer on the map, if a field is variable enough to call for different rates in different areas, or even no application in some areas. A table is displayed showing amounts added to or subtracted from the general fertilizer recommendation due to past or planned management of this field. The user can easily change certain information and compare effects of changes.

FLEXCROP is a microcomputer program model developed for the dryland farmer in the Great Plains (Halvorson and Kresge, 1982). This program helps farm managers evaluate the effects of their crop and soil management decisions on potential crop yield and to decide whether to crop or summer-fallow a given field. In the model, a percentage yield increase or decrease from a base yield is calculated for each management factor. The factors considered are previous crop, planned crop selection (such as spring or winter wheat, *Triticum aestivum* L.; barley, *Hordeum vulgare* L.; oats, *Avena sativa* L.; or safflower, *Carthamus tinctorius* L.), amount of stored soil water, growing season precipitation, variety selection, planting date, weed competition, soil fertility levels as determined by soil test, and crop nutrient requirements (fertilizer needed) to attain the predicted yield potential.

The FLEXCROP program calculates a yield potential based on the amount of plant-available water that the user entered. The plant-available water includes soil water, which is estimated by knowing soil texture and depth of moist soil, and growing-season precipitation, which the user can input or obtain from long-term weather records stored in the computer data base. This yield potential can be increased if a variety is to be grown that has a higher yield potential than the variety used in calculating the relationship between grain yield and plant-available water. Estimated grain yields are then reduced for late planting, poor crop rotations, poor weed control practices, and inadequate levels of plant nutrients.

The program makes a fertilizer recommendation that is based on soil test information user supplies and on the proposed method of fertilizer application (banded, broadcast, or a combination of both). The user is then asked to input the quantity of fertilizer to be applied. Grain yields are reduced if less than the recommended amount of fertilizer is to be applied. The user can then estimate economic returns based on this yield potential and the prices that are input.

CROPPAK, a modified version of FLEXCROP, adds the feature of precipitation probabilities and asks the user what risk level he wishes to accept in estimating yield potential (Leholm and Vasey, 1983). CROPPAK then makes a fertilizer recommendation based on yield potential, once other management factors such as planting date, etc., have been considered as was done in FLEXCROP. Another North Dakota program, WHEATPAC, is available for calculating potential and realistic yield goals for spring wheat by regions of the state (E.H. Vasey, 1985, per. com.).

CROPFILE is another version of FLEXCROP designed to serve as a file for storing data for a given field and for calculating yield potentials based on the information used in FLEXCROP (P.O. Kresge, 1985, per. com.). CROPFILE was developed in a spreadsheet format so that "what if" games can be played with the data base.

Numerous other programs, both simple and complicated, are available to assist in making crop management and soil fertility management decisions. Public and private advisory services need to start using the information and ideas from these programs to improve their fertilizer and crop management recommendations. The programs discussed here were used only as examples of how computers can be used in the crop management decision-making process.

Computers can rapidly store and access vast amounts of information. Why not use computers to help access the large volume of stored knowledge about crop management? Sharpley et al. (1985) have shown that soil P levels can be modeled fairly accurately and future soil test levels projected. Why not use such a model to project or predict a soil test P level, if current soil test P levels are not available but older soil test results are? Programs need to be developed that integrate or access numerous other programs that would help provide the information needed to make a more intelligent fertilizer recommendation.

Many farmers will rely on crop advisors and consultants to collect the pertinent crop data for use in computer models such as these. Many farmers will have several options for getting recommendations, but will probably use an agronomic advisor to help in the data handling. The exception will be the farmer who has an agronomic degree or a strong interest in technical aspects of crop production. The role of the Cooperative Extension Service will be important in linking farmers with timely computer recommendations. An increasing number of farmers may be able to use a microcomputer terminal and have access by telephone hookup to the crop advisor's office or soil analysis laboratory to obtain crop management information for a given field. The Cooperative Extension Service will need to play a key role in training crop advisors and consultants if the system is to function.

FUTURE NEEDS

The end result is that tomorrow's farmer expects to have answers to his agronomic questions. The crop consultant will be a key person on his management team. Many farmers will continue looking to crop advisors or consultants for a personal touch to crop production. This has been described as the human element that is part of the farmer's desire to have support in his management decisions. But in any case, either the farmer or the crop consultant will demand computer models and programs that given consistent and accurate recommendations. These individuals are looking to scientists for information.

Agronomic scientists need to supply or provide computer models for farmers to use, crop advisors, and consultants. Since advisors are customers of soil-testing laboratories, it is logical for the laboratory staff to work with the scientists on agronomic information transfer. A clear understanding of crop rotations, residue management, tillage practices, and fertilizer placement and timing enhance analytical results and recommendations.

Researchers need to become more aware of how their results can be molded to fill the voids in our knowledge base. They need to fit their results into current information-transfer models or develop models of their own that will be useful in information transfer by both private and public advisory services. We need to be mindful that the farmer is the end user of most of our agronomic data and information. Farmers are the ones who eventually put their livelihood on the line and apply the technical information supplied to them. Therefore, scientists and advisors need to do the best job possible in being sure the information they provide to the user is sound and meets current needs. The farmer's needs should be one of the main determinants of the work agronomic scientists undertake.

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