FUTURE DEVELOPMENTS IN SOIL SCIENCE RESEARCH

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INTERACTION OF SOIL FERTILITY WITH OTHER INPUTS IN CROP PRODUCTION FOR MAXIMUM ECONOMIC RETURN

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Optimizing economic returns to fertilizer application requires that plant nutrient supplies be adjusted to changes in other crop production factors. Factors that must be considered in optimizing profits include: 1) climate and soils; 2) plant-available water and yield potential; 3) tillage method and water conservation practices; 4) soil testing; 5) variety/hybrid selection; 6) plant populations and row spacing; 7) seeding date; 8) crop rotation; 9) weeds; 10) insects; 11) disease; 12) harvesting; and 13) marketing, crop quality, and price. Coordinating these factors requires an intensive crop management system and a positive attitude since the interaction of one, or more of these factors influences the magnitude of crop response to applied nutrients and/or net return. Some factors may not require action on the part of the grower. However, successful growers must know when to react to changes in the crop and to anticipate problems and conditions that warrant actions needed to maximize profits.

Discussed are the interactions of soil fertility with other crop production factors and their influence on economic returns, including projections of how these interactions may be managed in the future.

CROP PRODUCTION FACTORS

Climate and Soils

Temperature, precipitation, and length of growing season determine crop adaptation and greatly influence yield potential. To maximize profits from fertilization, only crops adapted to the local climate should be grown.

Soil physical and chemical characteristics influence yield potential. Soil compaction can reduce root growth and penetration as well as water and air movement in soil creating nutrient stress problems. Application of K may alleviate some of the detrimental affects of soil compaction (Table 1). Starter fertilizer has improved sorghum yields grown on a compacted soil (Table 2).

Soil acidity and salinity can limit crop yields and response to fertilization. Soil organic matter and parent material influence native soil fertility level and need for fertilizer.

Plant-Available Water and Yield Goal

Yield potential is directly a function of water available for plant growth in semi-arid and arid regions, particularly for

Table 1. Row banded K boosts corn yields on compacted soils. (L. Bundy, Dept. Soil Science, Univ. Wisconsin, Madison, unpublished data).

K Rate	K Soil Test	Compaction, metric tons <4.5	8.2	17.3	Maximum Yield Loss from compaction
kg/ha	mg/kg	------------- corn yield, kg/ha -----------			
0	102	8279	7150	6962	1317
42	102	10161	9533	9972	189

dryland crops. Soil texture affects the quantity of soil water available for crop use. Plant-available water (stored soil water plus growing season precipitation) can be used to predict yield potential. Halvorson & Kresge (1982) developed regression equations to predict yield potentials of several dryland crops.

The higher the yield potential, the greater the total N requirement needed to achieve this yield and maintain crop quality (Black & Bauer, 1986). Wheat generally requires about 40 g N/kg grain to optimize yields (Halvorson et al., 1986), corn about 23 g N/kg grain (Fixen, 1985). Determining yield goals based on available water is critical in estimating the total N needs of a crop for optimum economic returns.

Table 2. Starter fertilizer had greatest effects on no-till grain sorghum grown on a compacted soil (Touchton, 1985).

Sidedress N	Conventional Till no starter	Conventional Till plus starter*	No-Till no starter	No-Till plus starter*
kg/ha	------------------- grain yield, kg/ha ----------------			
0	2760	3450	2446	3136
45	4453	4579	3889	4516
90	5080	5206	4516	5331
134	5080	5080	4767	5770

Test: P, K, Ca, Mg all high; pH 6.1

* Starter Fertilizer = 112 kg/ha of 20-18-0.

To optimize profits (least cost per unit of produce), a producer should neither under- nor over-estimate a yield goal. Therefore, other yield limiting factors that can not be controlled by a producer should also be considered when establishing a potential yield goal and determining plant N requirements.

Tillage System

Tillage system can influence soil water storage, crop yield potential, nutrient availability, fertilizer placement method, and amount of fertilizer required. Immobilization of surface-applied N fertilizer by microorganisms and volitalization losses of some N sources in reduced and no-till systems can be reduced by banding the fertilizer (Table 3). Bandel (1985) also reported higher corn yields and better N use efficiency for no-till versus conventional till with 90 kg/ha or more of applied N (Table 4). Smika (1980) reported a 470 kg/ha dryland winter wheat yield advantage for a no-till compared to a conventional tillage system in the Central Great Plains because it had more stored soil water.

Soil Testing

Soil testing is essential for determining residual NO_3-N, and available P, K, S, and micronutrients. Proper soil sampling procedures are critical. Sampling of the surface soil layer (0-15 cm or tillage depth) is essential for all nutrients as well as pH, organic matter, and texture. Deeper soil depths (15-60, 60-120, 120-180 cm) need to be analyzed for NO_3-N, SO_4-S, and water content. Soil analyses are essential for determining fertilizer nutrient adjustments needed to achieve the estimated yield potential. Applying only those nutrients needed for average yields may maximize economic returns per dollar invested. However, higher yields may require soil test levels that are higher than those currently deemed adequate by soil test laboratories. Halvorson (1986) reported that a soil test level of 26 mg P/kg soil ($NaHCO_3$-extractable) was required to achieve 100% of the yield potential of wheat grown on a dryland loam soil using a wheat-fallow system in the Northern Great Plains. This is about 10 mg P/kg soil higher than normally recommended as being adequate.

Table 3. Four-year summary of the influence of N source and N placement on no-tillage corn yields, 1979-1982 (Bandel et al., 1984).

N Source	N Placement Method broadcast	injected	Mean
	---------- grain yield, kg/ha	----------	
Ammonium Nitrate	9653	9728	9690
Urea	7965	9584	8775
UAN (Urea-NH_4NO_3)	8950	9916	9433
Mean	8856	9747	

N rate = 134 kg/ha; LSD 0.05: N source = 263; N source x Placement = 376 kg/ha

Balanced plant nutrition is needed to profit from fertilization. Applying fertilizer N to a P deficient soil resulted in an economic loss, whereas an application of both N and P resulted in the greatest economic returns (Table 5). High P fertilizer rates or high residual P levels have induced Zn deficiencies in wheat (Singh et al., 1986) and in beans (Halvorson & Bergman, 1983).

Table 4. Grain yields for conventional and no-till corn with different nitrogen rates (Bandel, 1985).

Tillage System	N Rate, kg/ha 0	90	134	179	269	Mean
	---------- grain yield, kg/ha ----------					
No-till	1486	8499	10650	11892	11678	8844
Conventional	3820	8367	9646	10261	9508	8323
Mean	2653	8430	10148	11076	10593	8580

Note: Data points taken from best fit curvilinear regression.

Soil testing can identify nutrient imbalances in the soil and improve the accuracy of fertilizer recommendations.

Variety/Hybrid Selection

Variety or hybrid selection for specific site conditions can greatly influence yield potential, response to fertilization and profitability. A variety/hybrid's response to the environment affects both yield and crop quality. Selection should consider resistance to lodging, diseases, and insects under high fertility, high yield environments and/or sensitivity to low soil pH conditions. For example, Timian & McMullen (1986) found the spring wheat variety "Oslo" had a 33% reduction in grain yield when infected with the wheat streak mosaic virus versus a 98% reduction for "Olaf". Unruh & Whitney (1986) found that the winter wheat varieties "Newton" and "Tam 105" were extremely sensitive to low soil pH, high Al concentrations whereas "Hawk" and "Bounty 203" hybrid showed more tolerance to this soil condition with yields 3 to 4 times greater.

Table 5. Cumulative net dollar return above check treatment after harvest of 11 crops with the money discounted at a rate of 6.25%. The P fertilizer was only applied the first crop year (Halvorson et al., 1986).

Total P added	N Added Each Crop Year, kg/ha					
	0	45	90	0	45	90
kg/ha	cumulative net return, $/ha					
	- no protein premium -			- plus protein premium -		
0	0	-30	-70	0	28	8
22	79	137	54	72	203	142
45	149	309	238	144	380	346
90	170	481	358	162	559	491
180	160	469	407	138	553	528

Wheat = $0.121/kg; N = $0.51/kg 1st crop, NH_3-N = $0.35/kg crops 2-11; P = $1.035/kg; fert. application cost = $6.01/ha 1st crop & $10.34/ha crops 2-11.

Halvorson & Bergman (1985) found that selection of corn hybrid for its intended purpose of grain or silage production is critical. With the same level of N application, P-3978 yielded 3,100 kg/ha more grain than F-4195. In contrast, F-4195 yielded 2.5 Mg/ha more silage than P-3978. Tsai et al. (1984) also showed that corn hybrids vary in their response to N fertilization. Knowing how a variety or hybrid will respond to N fertilization is important for maximizing profits. Nutrient management systems need to be tailored to the genetic material being grown to optimize economic returns.

Plant Population and Row Spacing

Fertilizer responses can only be maximized if adequate plant populations and optimum row spacings are used. For example, winter wheat grown at a plant population of 4.3 million plants/ha and a row spacing of 10 cm is recommended for optimizing yields under humid conditions (Oplinger et al., 1985). In semiarid areas, 2.7 million plants/ha with row spacings of less than 30 cm are recommended (Murphy, 1987). Olsen (Table 6) found that as the plant population of two irrigated corn hybrids were increased, their response to higher levels of N application increased. These data indicate that larger nutrient responses, higher yields, and higher net returns are possible by matching hybrids with optimum plant populations, row spacings, and nutrient rates.

Table 6. Irrigated corn N responses are affected by hybrid and population at Rocky Ford, CO. (S.R. Olsen, USDA-ARS, Ft. Collins, CO, unpublished data).

		Nitrogen Rate, kg/ha		
Population	Hybrid	168	252	358
plants/ha		--------- yield, Mg/ha		
61,750	P-3183	12.0	12.2	12.4
	F-G4507	12.8	14.2	13.9
91,390	P-3183	12.2	13.4	14.4
	F-G4507	13.3	15.1	15.0

Seeding Date

Most crops have an optimum seeding date within each environment to optimize crop response and economic returns to fertilization. In the Northern Great Plains, greater responses of spring wheat to N and P fertilization are expected from early planting relative to late planting (Black & Siddoway, 1977). Sharratt et al. (1984) found decreases in spring wheat yields of 25-29 kg/ha/-day with delayed planting. Dryland winter wheat planted too early can use excessive stored soil water for fall growth, with increased plant disease potential while late planting can result in poor growth and increased winter kill. Hicks (1985) reported decreases in corn yield potential with delayed planting.

With adaptation of reduced tillage systems and early spring planting, responses to starter fertilizer placed with or near the seed at planting are expected because of cooler soil temperatures (Table 2). The interaction of crop varieties/hybrids with seeding time, tillage systems, fertilizer placement, and soil temperature needs to be elucidated so that nutrient management systems can be developed for optimizing yields and economic returns.

Crop Rotation

Rotating crops within a cropping system has advantages over monoculture systems which often develop severe disease, insect, and specific weed problems that are hard to control chemically and generally have lower yields because of these problems. Thus, response to fertilization is greater when rotation cropping systems are used. Including legumes in a cropping system can reduce N requirements of succeeding crops (Table 7). Fertilizer recommendations need to consider the previous crop grown and adjust fertilizer N rates to give credit for N fixed by legumes. Previous crop can also affect the quantity of available subsoil water and consequently the yield potential of the following crop (Black & Bauer, 1986).

Table 7. Rotating corn with soybeans for higher corn yields in the Morrow Plots, University of Illinois. (Odell et al, 1982).

N Rate	Continuous Corn	Corn-Soybeans	Yield Advantage
kg/ha/yr		grain yield, kg/ha	
0	4704	6899	2195
134	7652	9471	1819
179	8091	9784	1693
224	8279	9784	1505

Weeds, Insects, and Disease

Weeds growing within a crop or cropping system will reduce yield potential because weeds compete for water and nutrients. Therefore, lack of weed control will reduce crop response to applied fertilizer as well as lower crop quality. Application of NH_4-bearing fertilizers and high levels of soil N have improved the performance of some herbicides in growing crops (McKercher & McGregor, 1980; Nalewaja & Woznica, 1985). The economics of taking action versus no action in controlling weeds in the growing crop needs to be carefully evaluated for both the short- and long-term effects. A "best" herbicide weed control program should be utilized for each crop in a rotation for best long-term economic returns.

Any infestation of insects or diseases that reduce crop yield will reduce crop response to fertilization. High soil fertility promotes lush vegetative growth and thicker canopies which can enhance the possibility of certain disease infestations. On the other hand, plants growing under high soil fertility conditions are healthier and more resistant to diseases (Usherwood, 1980; Jackson, 1986). Application of 60 or 90 kg N/ha to spring wheat grown after sunflowers significantly reduced leaf spot diseases compared to 30 kg N/ha (J. Krupinsky, 1986, USDA-ARS, Mandan, unpublished data).

Harvesting

Timely harvest operations with properly adjusted equipment reduces harvest yield losses and enhances the economic returns to fertilization. Delayed harvest can result in yield loss due to wind, hail, rain, and frost damage and decreases in crop quality. Adequate levels of plant nutrition may advance the maturity date and allow earlier harvest. Benefits of P fertilization in increasing yields, advancing crop maturity, and cutting crop drying costs are shown in Table 8. Potassium reduces lodging, thereby reducing harvest losses (Usherwood, 1980). Final net returns from fertilization needs to be calculated on the basis of higher yield, improved grain recovery, and lowered drying costs.

Marketing, Crop Quality, and Price

Advanced contracts for purchase of the crop or sufficient storage should be available to allow marketing to take advantage of crop quality, including grain protein, to obtain the highest possible price. Grain protein and economic returns (Table 5) can be improved by N fertilization (Halvorson et al., 1987).

Table 8. Effect of phosphorus fertilization on yield and moisture content of corn in Ohio (Dr. Jay Johnson, Ohio State University; Eckert, 1978).

P added	Grain yield*	Grain moisture*	Drying costs*	Drying costs
kg/ha	kg/ha	%	cents/kg	$/ha
0	9,095	27.0	0.91	83
10	9,879	26.0	0.82	81
20	10,600	25.5	0.78	83
40	10,914	24.6	0.71	77
60	11,227	24.2	0.68	76

Bray Soil P = 18 kg/ha

* Average of 1976 and 1977 data.

Crop and fertilizer price and the expected crop response to added fertilizer influence the quantity of fertilizer that can be applied to optimize economic returns. Generally, if it is economical to plant a crop, it will be profitable to fertilize the crop with the nutrients required for optimum yield and quality.

FUTURE MANAGEMENT OF SOIL FERTILITY

All production factors that influence crop response to soil fertility level must be considered to optimize farm profits. Understanding and integrating the interactions of crop production factors and their effect on crop yields and economic returns is a very complex problem. As our understanding of these complex interactions unfold, computer models and artificial intelligence systems will be essential for making intelligent and reliable decisions regarding soil fertility management. Future models must integrate information from other agronomic, climatic, and watershed models to help make management decisions as to what level of nutrients should be applied to crops to obtain optimum economic returns. FLEXCROP (Halvorson & Kresge, 1982) and CROPPAK (Leholm & Vasey, 1983) are examples of crop management models that are currently available, but need to be expanded and made available to farmers, Extension Service personnel, agronomists, crop consultants, fertilizer industry, and other agribusiness people. Data bases will need to be kept current with new crop variety, weed, disease, and insect control information updated annually for models to be most useful and effective.

Computers can potentially be used to maintain soil fertility balance sheets and soil test information for a given soil or field. This approach would involve an intensive initial soil sampling program to collect baseline data for predicting changes in soil test values based on crop removal of nutrients, soil physical and chemical properties, and amount of fertilizer applied. In the future, such nutrient balance models may more accurately estimate fertilizer requirements of crops than using annual soil testing procedures. Declines in soil test values can probably be predicted, knowing amount of fertilizer applied, leaching losses, and fixation properties or characteristics of a given soil (Barber & Kovar, 1985). Predicting nutrient availability in this manner may eliminate the need for soil testing every crop year.

A challenging task for future soil fertility researchers is that of devising soil sampling techniques to assess the fertility status of reduced tillage fields with localized fertilizer placement. Current soil tests are generally calibrated on "plow layer" samples. With different degrees of tillage and fertilizer incorporation, the term "plow layer" takes on a dubious meaning. Future soil test calibrations need to consider variety/hybrid selection, planting date, plant population, fertilizer source and placement, tillage systems, and other intensive crop management practices. Identifying soil test levels needed to attain the higher, more profitable yields associated with recent intensive crop management systems becomes a future challenge (Murphy, 1983). Future soil test and nutrient correlation work should use intensive crop management systems, higher rates of nutrients than those used in the past, and evaluate the effects of P, K, and other nutrient distributions throughout the root zone on crop yield potential. A better understanding of the volume of root zone that must be fertilized to optimize crop yields and economic returns is needed.

Fertilizer recommendations in the future will become more sophisticated with potential environmental and economic impacts being evaluated before any fertilizer is applied. Detailed soils, fertilization, and cropping information, including field maps showing different soil types across a field and recommended fertilizer rates for each soil type will become a necessity. A fertilizer management model, SOIL PLAN, uses the mapping idea for making fertilizer recommendations for corn based on soil type across a field (Wisiol et al., 1985).

Fertilizer applications will vary based on need for each soil type in a field and will be controlled by portable computer systems in the applicator. Proto-types of this type of fertilizer application equipment are already being tested and refined (Schmitt et al., 1986). The ability to apply plant nutrients variably across a given field according to need by soil type will greatly enhance the profitability of fertilizer applications. In addition, protection of the environment should be improved with less potential for ground water and stream contamination because over-fertilization of a particular soil in a field would be less likely.

The soil fertility expert of the future will not only feel comfortable with computer technology, but will not be able to function adequately without it. Artificial intelligence systems will serve to answer many of the routine problems while the soil fertility specialist conducts research and develops new information to better understand the interactions of plant nutrition with all factors that affect crop production. Twenty years from now, nutrients other than N, P, K, S, Zn, and Fe may become more limiting and new management information will be needed. As new varieties are released and new crops are adapted to new production areas, researchers will need to generate the information required to manage the nutrient needs of these crops. Complex interactions such as the relationship of NH_4^+ and NO_3^- in promoting higher yields (Olsen, 1986) will be understood and blended into fertilizer recommendations to optimize crop responses to N fertilization.

The more comprehensive involvement of soil fertility research with other disciplines in the future centers on an increasing need for optimizing productivity per unit of land with the dual objective of providing more food and fiber AND keeping the producer profitable. Generally, as crop productivity levels improve, profitability also improves. Future soil scientists and crop management people will have to look to continued improvement in productivity per unit of input cost as a means of maintaining economic viability of agriculture in the next 20 years. We would like to leave you with the impression that everything hasn't been learned in the area of soil fertility, and that crops and soils production research in the next 20 years will be an extremely exciting and rewarding field in which to work.

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