Optimum Fertilizer Use with Differing Management Practices and Changing Government Policies

J. T. Thorup[1] and J. W. B. Stewart[2]

[1]Chevron Chemical Co., Mission, Kansas and [2]Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, Saskatchewan S7N 0W0

ABSTRACT

Fertilizer use may be affected by various factors. Changes in cropping systems such as adoption of no-till practices may require more fertilizer, different forms of fertilizer or greater attention to placement of fertilizer materials. Response of crops to residual phosphorus and other nutrients may determine fertilizer practices to achieve optimum economic returns from fertilizer application.

Improving the effectiveness of communications between those who develop new technology and those who use it is a challenge we face in agriculture today. Educational programs are being provided by several interested groups. Good cooperation among these groups is essential if farmers and fertilizer dealers are to get the maximum benefit from these programs.

Government policies such as acreage reduction, conservation reserve and clean water legislation greatly affect fertilizer use. These programs must be evaluated carefully with input from knowledgeable people before being imposed upon the agriculture industry.

Management practices such as maximum economic yield (MEY) encourage the use of optimum fertilizer applications. These practices should be encouraged as a means to maximizing the efficiency of crop production programs.

INTRODUCTION

In 1986, on the occasion of the Golden Anniversary of the Soil Science Society of America, leading soil scientists considered in detail the important research needs for the future (Boersma, 1987). Several authors commented on the change of focus over the past 50 years from the single goal of optimizing crop production to the emerging goal of simultaneously balancing the need to optimize crop production with that of preservation of environmental quality. In this regard, conservation tillage systems or "minimal" tillage systems (see definition, Conservation Technology Information Center, 1985) have increased from approximately 5% to 35% over the 50-year time period and were projected as continuing to increase, even to the extent that one projection has 95% of the planted crop land in the United States using some form of conservation tillage by the year 2010.

In keeping with this trend, fertility management in the future will stress maximizing the efficiency of nutrient recovery in order to optimize production and reduce costs. Knowledge of effectiveness of seed and nutrient placement will have to be balanced against the need to minimize tillage operations. This will require a much greater understanding of the effect of conservation practices on the management of plant nutrients and their eventual redistribution and fate. Added to this will be the need to understand market pressures and the flexibility to take advantage of this knowledge. In addition, governments will continue to be under much political pressure to preserve the capability of food production through the maintenance of a viable and healthy farming community. For legislators the toughest challenge will be to separate measures that are important from those that are expedient. Choosing expedient solutions is always tempting but has led to failure in the long run. In this paper we attempt to examine these varying pressures and to suggest how they will be handled. Developing strategies which include achievement of maximum economic yield, optimum fertilizer use efficiency, soil improvement and minimum degradation of the environment by fertilizer use requires both careful management practices at the farm level and clear-sightedness in the legislative assemblies.

CONSERVATION TILLAGE AND FERTILIZER USE

Conservation practices influence the fate of plant nutrients in cropping systems (Fig. 1). The degree of influence of conservation practices on the amounts of plant nutrients removed in the harvested crop, lost to the environment or remaining in the soil for subsequent crop use has to be evaluated for particular soil types and locations. Key to much of this discussion is a knowledge of how the

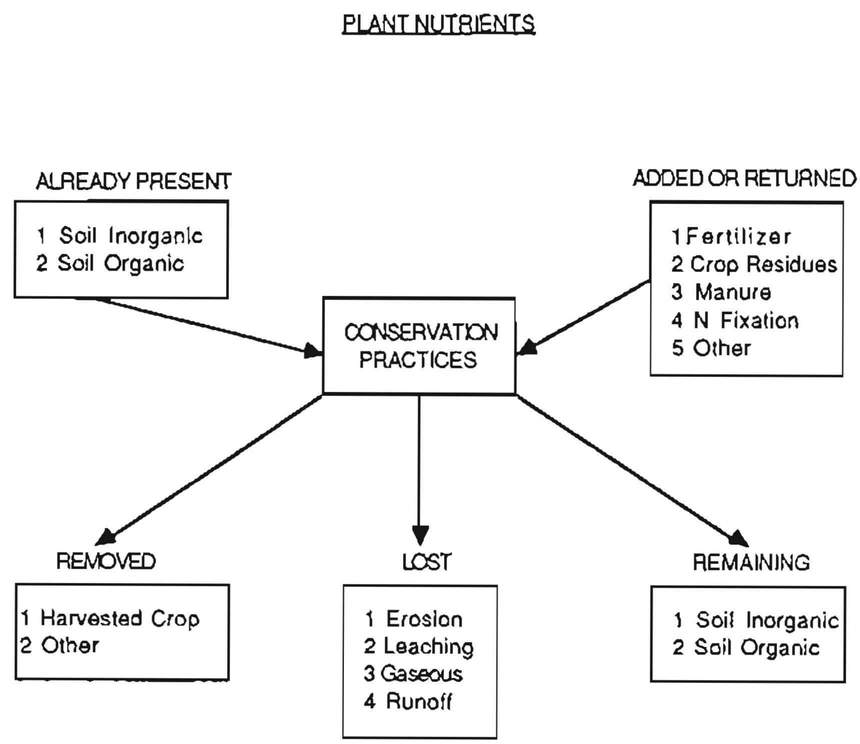

Fig. 1. Conceptual role of conservation practices in the management of plant nutrients and their eventual redistribution and fate. (Source: Follett et al., 1987a.)

management system influences the natural cycling of nutrient elements. This topic was discussed in detail in an earlier symposium (Follett et al., 1987b). In particular, the timing of needed fertilizer inputs and the efficiency will be greatly affected by the type of soil conservation and management system approach.

Agriculture management systems control crop residue placement, soil disturbance and *in situ* production of soil organic matter. The resultant effects on soil physical properties, substrate availability and organism habitat greatly influence plant, faunal and microbial activities and the cycling of C, N, P, S and other nutrients. Interactions between the soil physical, chemical and biological characteristics with various systems of organic matter management are greatly influenced by climate, soil and addition of soil organic matter. Development of alternate management strategies for most efficient utilization of N and other nutrients requires better understanding of these interactions in the soil ecosystems. During the past decade much of this research work has been carried out at the process level. The optimum balance between organic matter exploitation and its subsequent effect on soil physical properties such as soil erosion or soil chemical properties that influence soil fertility needs to be worked out. We must determine how much organic matter can be manipulated and how much it can be managed.

NUTRIENT CYCLING

Studies of soil organic matter and nutrient cycling (N, P and S) emphasize the central role of C in nutrient cycling (Stevenson, 1986; Follett et al., 1987a). In a system in dynamic equilibrium with interchanges governed by chemical, physical and biological interactions, microbial activity is often depicted as a wheel rotating in the soil in response to energy (C) inputs and having a central role in nutrient transformations (Stewart and Sharpley, 1987). Management often changes the timing of C inputs and thus the management of C in turn can manipulate nutrient availability.

Natural systems have evolved in a manner that conserves nutrients. As an example, nitrogen is rarely lost in large quantities by any process in unfertilized grassland. Immobilization and mineralization processes are in synchrony with plant uptake that results in minimal nutrient losses. Crop production systems that mimic natural systems in terms of lack of soil disturbance and return of crop residues to the soil help maintain the synchrony of nutrient cycling processes and minimize nutrient and organic matter losses. In the past, soil degradation from poor management occurred even though short-term, high crop production levels were obtained. With good management, sustained high levels of crop production provide excellent opportunities to significantly improve soil properties and their long-term productivity. High levels of crop production often introduce larger quantities of crop residues into soils. Differences exist between plow-tillage and no-tillage with regard to timing of crop residue inputs. This can affect nutrient cycling and balance. Similarly, the quality of organic waste inputs.(e.g. straw vs. legume vs. animal manure) affects nutrient composition in the soil solution and future nutrient supplying power of the soil. Obvious examples of this occur with the dynamics of soil and fertilizer nitrogen (Doran and Smith, 1987; McGill and Myers, 1987). While this has been well documented with regard to nitrogen, it is less well known with regard to phosphorus and sulfur. In fact, the limitations of many of the present soil test methods for phosphorus and sulfur are that they only measure inorganic forms in the soil and do not properly account for the contribution from mineralization of organic forms and past management histories (Stewart and Sharpley, 1987). Inclusion of the contribution of organic matter mineralization has to take into account the seasonality of phosphorus and sulfur turnover. This is especially important with a more widespread adoption of soil conservation oriented management practices.

In addition to the diagnostic criteria required to quantify the fertilizer requirements for soil, a secondary problem arises with regard to placement methods. Much soil fertility research has been directed towards the efficient utilization of phosphate fertilizers through use of placement technique such as placing fertilizer close to or in bands adjacent to the seed. Some of the requirements of placement run contrary to the requirements of soil conservation and it is only recently that equipment, such as air seeders, has been developed that allows one both to seed and to place fertilizer in no-till systems. Nonetheless, in certain soils that are relatively unweathered, the possibility does exist to utilize residual phosphate fertilizer (Roberts and Stewart, 1987). However, the feasibility of broadcast placement versus seed placed or banding has to be examined in the context of the soil chemical and physical properties and also with regard to adequate soil conservation.

CHANGES IN CROPPING SYSTEMS

The adoption of conservation tillage systems has increased greatly over the past several years. In the U.S., for example, conservation tillage was used on almost one-third of the production acres (100×10^6 acres) in 1987 (CTIC, 1987). In the more humid regions of the U.S., reduction of soil erosion by wind and water and protection of water quality have been primary concerns of conservation programs. In the more arid regions, conservation of soil moisture has also been a major goal of stubble management (Stewart, 1987) allowing for improvement in the potential yield for crops in many areas and a shift from summerfallow to annual cropping in others. The probability of increased production from these changes in cropping systems has created a need to examine fertilizer programs more closely. Many researchers have studied the effects of conservation tillage on crop production. Much has been learned with respect to optimizing net returns using the various reduced tillage systems. Adoption of conservation tillage has been enhanced by development of both equipment and chemicals to facilitate farming in residues.

Proper placement has been recommended to maximize the efficiency of fertilizers with conservation tillage practices. Nitrogen broadcast on the surface may be immobilized by the increased microbial populations associated with crop residues at the soil surface. While this N is not lost from the system, the timing of N availability has been altered. Urea containing fertilizers, both liquid and dry, are subject to significant losses of nitrogen by volatilization if they are broadcast on the soil surface, unless precipitation (or irrigation) in amounts greater than 0.5 inch occurs within 48 hours after application to move urea into the soil prior to hydrolysis.

In many cases, injecting nitrogen into the soil below surface residues is preferred. Banding on the surface in concentrated bands is another option which has been shown to be more efficient than surface broadcast applications. For example, placement with urea ammonium nitrate (UAN) on no-till corn grain yields (Table 1) show that the surface band (dribbled) of UAN increased yields by 12 to 36 bu $acre^{-1}$ over broadcast applications at various sites. However, injection of UAN resulted in up to 10 bu $acre^{-1}$ more yield than surface banding.

Table 1. Influence of N source and placement on no-tillage corn grain yields, 1982.

N Treatment	Wye[1]	Poplar Hill[1]	Poplar Hill[1]	Poplar Hill[2]
	bu $acre^{-1}$			
Check	33.3	31.1	42.3	42.3
Ammonium nitrate broadcast	112.4	155.1	141.9	163.6
UAN broadcast	99.0	119.9	136.3	159.0
UAN dribbled	119.9	156.6	148.9	176.0
UAN injected	124.2	167.2	156.2	178.4

[1]120 lb N $acre^{-1}$
[2]160 lb N $acre^{-1}$
Source: Bandel, 1984, University of Maryland.

Yields of corn (Table 2) have been increased under no-till compared with conventional tillage practices (Hargrove, 1985; Bandel, 1983). Reasons for greater yield include improved water infiltration and use with no-till. Several researchers have found that there can be a need for higher N and P fertilizer use to take advantage of the added yield potential. It has also been shown that after adoption of no-till systems for periods over 10 years there has been a buildup of mineralizable N such that higher yields are achieved with reduced N inputs (Table 3) (Doran and Smith, 1987).

Phosphorus fertilizer application rates are also affected by changes in tillage practices. These range from increased P requirement due to increased yield to reduced P inputs owing to cycling of organic P (Stewart and Sharpley, 1987). Phosphorus placement either in a band with N below the seed or seed placed have generally been the most effective means of applying fertilizer P if judged on a one year basis. In neutral calcareous soils such as in the Dakotas or western Canadian prairies, where transformations of applied P to less available forms is a slow process, broadcasting single applications of P can sustain cereal production for several years.

Recent studies in Saskatchewan and Manitoba have shown residual applications of fertilizer P to yield as well and often better than annually applied seed-placed P for periods of up to 8 years. One study, in Saskatchewan, found a combination of a large single P application with annual seed-placed treatments produced a better yield than either treatment applied alone (Fig. 2). In this trial, the maximum yield required a total fertilizer input of 200 lb P $acre^{-1}$ (90 lb P $acre^{-1}$

broadcast initially and 22.4 lb P acre^{-1} applied annually) over a 5-year period. Two other combinations, a broadcast application of 45 lb P acre^{-1} with 11 lb P acre^{-1} seed-placed annually and a broadcast application of 90 lb P acre^{-1} with 2.8 lb P acre^{-1} seed-placed annually, produced yields greater than 95% of the maximum and only required a total of 100 and 104 lb P acre^{-1}, respectively over a 5-year period.

Table 2. Grain yields from conventional and no-tillage corn following variable nitrogen rates, 1981.

Tillage	N (lb acre^{-1}) 0	80	120	160	240	Avg.
	bu acre^{-1}					
			Poplar Hill Research Farm			
No-tillage	24.1	125.5	168.1	193.0	187.2	139.6
Conventional	66.2	139.9	154.6	162.3	158.7	136.3
Average	45.2	132.7	161.4	177.6	173.0	138.0
			Wye Institute			
No-tillage	72.5	148.1	174.8	185.1	190.2	154.3
Conventional	103.3	168.2	168.9	172.8	175.2	157.7
Average	87.9	158.2	171.9	178.9	182.7	155.9
			Plant Research Farm			
No-tillage	23.5	107.5	135.7	134.6	147.0	109.9
Conventional	50.3	70.3	95.8	108.3	78.2	80.6
Average	36.9	88.9	115.8	121.5	112.6	95.1
			Forage Research Farm			
No-tillage	67.0	153.9	167.7	168.8	161.5	143.4
Conventional	95.6	156.7	141.8	151.1	158.4	140.7
Average	81.3	155.3	154.7	158.9	160.0	142.1

Source: Bandel, 1984, University of Maryland.

In the above study, detailed investigations of the forms of applied P remaining in the soil showed that after 5 years, less than 15% had been converted to unavailable forms. This remaining fertilizer P should be available for subsequent crops for many years.

When applying high rates of fertilizer P, the potential interaction with other nutrients must be considered. Research has shown that maximum residual crop response to applied P can only be expected if sufficient fertilizer nitrogen was supplied or available nitrogen was present in the soil. Significant interactions between applied P and micronutrients have also been found (Wagar et al., 1986; Singh et al., 1986). Zinc is of particular concern. High application rates of P are

Table 3. Effect of tillage management on soil water and organic matter contents and levels of microbial biomass and potentially mineralizable N.

	Relative difference no-tillage vs. conventional tillage			
Location(s), depth in soil	Water content	Organic matter	Microbial biomass	Potential mineralizable N
-----------inches-----------	%			
USA (six sites)				
0-3	+22	+40	+58	+34
3-6	+3	-1	-2	-3
6-12	+5	-7	0	-7
Canada (four sites)				
0-2	-4	+11	+11	+59
2-4	+2	-2	-6	-25
4-8	-	-	-6	-
England (one site)				
0-2	+2	+16	+32	-

Source: Doran and Smith, 1987.

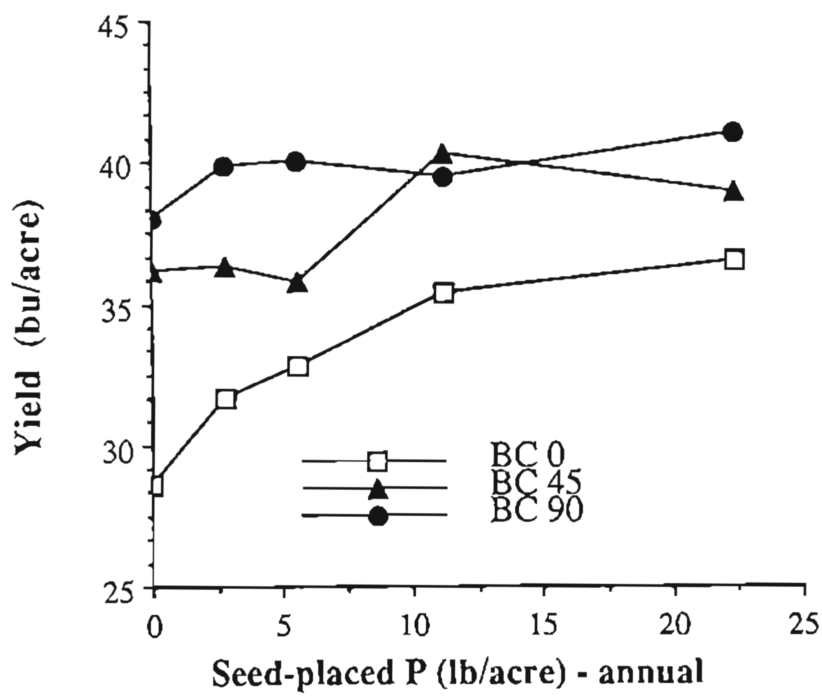

Fig. 2. Grain yields (5-year means) from plots receiving broadcast P treatments of 0, 45, 90 lb P acre^{-1} and annual seed-placed treatments of 0, 2.8, 5.6, 11 and 22.5 lb P acre^{-1} (Roberts and Stewart, 1987).

known to induce a zinc deficiency which can have a yield-limiting effect. However, this deficiency can be alleviated by the application of zinc fertilizer.

The apparent long-standing effects of residual fertilizer P offers several agronomic advantages for crop production. A moderate to large one-time application of fertilizer P provides a viable alternative to the traditional approach of applying small amounts of P annually with the seed. A large single application of P prior to initiating reduced tillage parctices could be particularly important in supplying the P requirements for future crops. Residual P applications also provide a means of overcoming the variable P deficiency that is commonly associated with eroded knolls and leveled land. Other advantages include supplying P for crops such as canola or flax which are sensitive to large amounts of fertilizer P placed with or close to the seed.

The question arises as to the profitability of residual P applications. Cost benefit analysis using Saskatchewan yield data, current fertilizer P costs, simulated grain prices and discount interest rates has shown that 90 lb P acre^{-1} broadcast initially can be as economically viable as 22.5 lb P acre^{-1} seed-placed P applied annually over a 5-year period (Table 4).

Table 4. Net present value ($ acre^{-1}) of return for dollars invested in fertilizer† for an initial single broadcast P application and annual seed-placed P applied consecutively for 5 years.

Interest rate	Grain price ($ bu^{-1})					
(%)	4.08*	6.12	8.16	4.08	6.12	8.16
	Broadcast 90 lb P acre^{-1}			Seed-placed 22.5 lb P acre^{-1}		
	Net present value ($ acre^{-1})					
8	128.47	206.36	284.25	96.25	180.30	249.77
10	122.61	197.56	272.25	104.94	171.00	237.06
12	117.19	189.43	261.66	99.52	162.44	225.36

† Assumes a P fertilizer cost of $0.35/lb P or $0.15/lb P_2O_5.
* Note: This data taken from Roberts and Stewart (1987) which expressed the data using metric units. Hence, grain prices of 150, 225 and 300 $/tonne become 4.08, 6.12 and 8.12 $ bu^{-1}, respectively.

Thus, the utilization of residual fertilizer P may now be considered a viable management option for cereal production, particularly in the calcareous, high pH Mollisols. Residual application of fertilizer P may not be practical in areas with lower pH soils (i.e. less pH 7.0) because of the formation of different fertilizer reaction products of lower solubility.

Starter fertilizers are recommended for conservation tillage. Crop residues insulate the soil surface causing soils to remain colder for a longer period of time in the spring. Increased soil moisture under conservation tillage also causes soils to remain colder for extended periods of time. Soil temperatures (Table 5) remain as much as 5 or 6 ° F lower in reduced tillage plots compared to plowing (Griffith et al., 1977).

Table 5. Mean soil temperature over the first eight weeks after planting.

	Northern Indiana		Eastern Indiana	Southern Indiana
Tillage system	Tracy sandy loam	Runneymede loam	Blount silt loam	Bedford silt loam
	Soil temperature (°F)			
Spring plow	72.4	71.0	75.8	79.0
Chisel	68.1	67.2	72.4	75.6
Ridge till	69.9	69.4	74.1	77.2
No-till	65.9	64.7	71.7	74.2
Avg. planting date	April 27	May 2	May 14	May 6

Source: Griffith et al., 1977.

Phosphorus uptake by corn is influenced by temperature and soil compaction (Barber, 1984). Diffusion of P to roots is slower at lower temperatures and higher bulk densities. Less root exploration under these conditions also depresses nutrient availability. Starter fertilizer use under these conditions will usually result in plant growth and yield responses. Other benefits observed from use of starter fertilizer include earlier maturity, earlier silking and tasseling and lower moisture at harvest. Sometimes corn and grain sorghum in conservation tillage systems yield less than in conventional tillage systems. Starter fertilizer can increase conservation tillage yields to equal or higher than those with conventional tillage. Such starter fertilizer needs in conservation tillage will not be predicted from soil test levels of P and K (Touchton, 1985; Eckert, 1985).

The use of starter fertilizers will increase as conservation tillage acres expand and will be facilitated by the continued improvement of equipment which makes starter applications even more convenient.

Other changes in cropping systems will increase the need for fertilizer. A change from wheat-fallow to annual cropping in some areas and to wheat-grain sorghum-fallow in others will increase grain yields and require adequate fertilization. Technology will increase to provide more uniform infiltration of water into soils. Improvements in this area will lead to still further crop yield increases and reduced leaching losses of mobile nutrients.

EDUCATION PROGRAMS

One of the challenges we face in agriculture today is to improve the effectiveness of communications between those who develop new technology and those who use the concepts to improve production practices. For instance, despite much research and technology transfer, about 5% of the western Great Plains dryland winter wheat growers are using P fertilizers while approximately 33% of the area's acreage is deficient in P. Similarly, in the Western Provinces in Canada where soil testing laboratories were set up in the mid 1960's following 10 to 20 years research into the N and P fertilizer requirement of spring wheat, both N and P fertilizer use fall short of requirements, sometimes by as much as 50%.

It is apparent that results from research are being adopted very slowly by growers and that new means of technology transfer must be found (Olson and Beaton, 1987; Ward et al., 1987). The basic ingredients of technology remain - these are good research and practical clear demonstrations followed by development of informational data banks to be used to transfer information to producers. There are many examples of this type of program. For instance, Havlin (1988) showed a good example of N and P interaction based on 13 years of data (Fig. 3) which clearly demonstrates the profit margin using current prices (Table 6). Havlin showed a response on winter wheat from phosphate applications up to 60 lbs per acre on low P soils (Table 7).

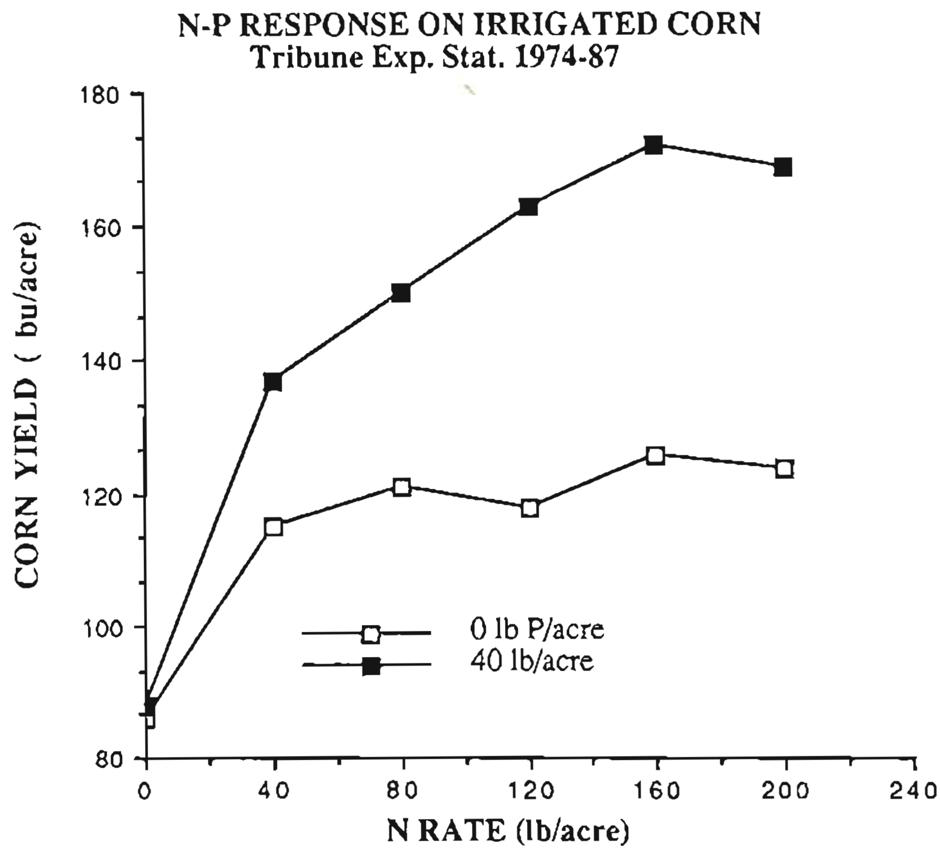

Fig. 3. Response of irrigated corn to N and P applications (from H ıvlin, 1988a).

Table 6. Economics of N and P fertilization of irrigated corn.

P rate	Optimum N rate	Net return	Return/ fert. $
lb acre^{-1}		$ acre^{-1}	
0	80	76.00	1.30
40	170	176.00	1.62

Source: Havlin, 1988b.

Table 7. Effect of phosphorus on wheat grain yields at six locations in western Kansas.

P_2O_5 rate	County location					
	Ford	Gove	Trego	Finney	Greeley #1	Greeley #2
lb acre^{-1}	bu acre^{-1}					
0	26.4	29.2	43.4	32.8	44.3	38.6
15	29.5	31.5	47.7	36.6	52.1	42.1
30	39.7	33.7	48.5	41.8	52.9	42.1
45	40.8	37.2	52.6	39.8	50.6	41.6
60	46.4	36.0	48.5	43.4	53.2	45.2
75	44.5	35.5	51.5	40.8	50.2	41.9
LSD (.05)	6.0	4.4	4.7	5.0	5.5	4.3
C.V. %	12.2	10.4	7.8	10.2	8.8	8.3
Melich P ppm	7	9	8	9	14	19
Bicarb P ppm	4	5	4	5	8	10

Source: Havlin, 1988a.

The second step in educational programs is getting the information to growers and fertilizer dealers. Many organizations exist today whose goals are to educate those individuals who are engaged in production agriculture with the result that thousands of bulletins, handbooks, and other written materials are available at no cost to the farmer (Olson and Beaton, 1987). Hundreds of conferences, workshops, grower meetings, etc. are sponsored by these groups each year to explain fertilizer concepts and answer questions to help growers understand fertilizer programming.

The final step in the educational process is adoption by the growers and fertilizer dealers. A concentrated effort is needed by all the educational groups to encourage individuals to try these programs on their own fields with their own management skills. This appears to be the most difficult part of the educational process. Farmers, like many of the rest of us, resist change. They are comfortable with the systems they have become accustomed to using.

Fortunately there is a group of "innovators" among farmers, soil testing agencies and fertilizer dealers who enjoy the challenge of something new (Ward et al., 1987). These will be the first to adopt new ideas, incorporate computer technology into transferring these ideas, and even develop some of their own. These are the individuals who will eventually lead the others into adoption of new programs and utilization of the storehouse of information being developed by researchers.

GOVERNMENT PROGRAMS

Both Canada and the United States of America government programs have greatly affected fertilizer use and demand. These programs fall into two main classes: 1) those that are dictated by the nation's ability to sell its produce and 2) those that are dictated by environmental concerns related to soil and water quality and conservation needs. The 1985 U.S. Farm Bill has resulted in a sizeable reduction of crop acres. Acreage Reduction Programs (ARP) including mandatory reductions and voluntary paid land diversions along with the long-term Conservation Reserve Program (CRP), have reduced total principal crop acreage planted to about 305 million acres. This is down approximately 60 million acres from the 1981 principal crop average.

As carry over stocks of corn, wheat and soybeans decline, ARP acreage will be adjusted to allow more acres to be planted. CRP acres are targeted for 40-45 million acres by 1990. Many of these highly erodible soils probably never should have been cultivated.

Analysts (U.S. and World Fertilizer Service, 1987) have forecasted an increase in corn, wheat and soybean acres over the next 8 years. Forecasts for corn show a growth from approximately 65 million acres in 1987 to 73 million in 1996. Wheat shows a growth from about 66 million acres in 1987 to 77 million in 1996. Soybeans have been forecasted to increase from 57 million acres in 1987 to 63 million in 1996. These increases are reflected in projected fertilizer use (Table 8).

Regulations dealing with groundwater quality will also impact fertilizer use. Some states have already initiated programs. Recent legislation in Nebraska, for example, requires that groundwater quality be protected. The Natural Resources Districts (NRD) across the state have been given the responsibility to develop and carry out the necessary programs. In response to this charge, the Central Platte NRD had regulations already in effect for the 1988 crop.

Areas of the district are classified as phase I, II or III based on nitrate-nitrogen in groundwater. In phase I areas (less that 12.5 ppm nitrate-nitrogen), the only requirement is that commercial nitrogen fertilizer cannot be applied on sandy soils in the fall and winter (prior to March 1). In phase II areas (12.5 ppm

Table 8. United States annual agricultural fertilizer use fertilizer years, 1970-1996.

	Nitrogen (N)		Phosphate (P_2O_5)		Potash (K_2O)		Total	
	Mil. tons	% Change	Mil. tons	% Change	Mil. tons	% Change	Mil. tons	% Change
1970	7.459	7.2	4.574	-2.0	4.036	3.7	16.068	3.6
1975	8.601	-6.1	4.507	-11.6	4.453	-12.4	17.561	-9.2
1980	11.406	6.4	5.431	-3.1	6.245	0.0	23.082	2.3
1985	11.493	3.6	4.658	-5.0	5.553	-4.2	21.704	-0.4
1990*	10.003	1.3	3.925	1.1	4.827	1.3	18.755	1.3
1995*	11.403	2.1	4.547	2.5	5.533	2.3	21.483	2.3
1996*	11.611	1.8	4.640	2.0	5.654	2.2	21.905	2.0

Source: U.S. and World Fertilizer Service, 1987.

to 20 ppm nitrate-nitrogen), additional regulations apply including mandatory testing of soils to a depth of 3 feet, irrigation water testing, and an annual report by farmers to the district. Phase III areas (above 20 ppm nitrate-nitrogen) have two additional regulations. Fall fertilizer nitrogen applications are banned on all land and split applications of nitrogen or use of an approved inhibitor if all nitrogen is applied preplant is required.

At the present time amounts of nitrogen to be applied are not regulated. It is suggested that nitrogen fertilizer applications be adjusted to take advantage of nitrogen present in soil and water. Multiple applications of nitrogen and use of nitrogen stabilizers to slow nitrification are encouraged by the NRD.

One of the better means to improve nitrogen utilization and reduce nitrogen losses is to balance nitrogen with phosphorus and potassium. Many researchers have shown increased utilization of nitrogen when applied with phosphorus.

FUTURE NEEDS

Farmers have very little control over the price they receive for their crops. Supply and demand on a worldwide basis dictate largely what a crop will sell for. In order to be competitive in a worldwide market and maximize profits, a farmer must produce crops for the lowest possible unit cost, and simultaneously maintain the quality of land resources. This does not mean cutting costs to the point of reduced productivity. It requires careful attention to many factors.

One of the keys to lowest unit cost is increased yields. This spreads production costs over a larger base and cuts the cost per unit. The yield which gives the highest possible net return per acre has been called Maximum Economic Yield (MEY). Environmental concerns must go hand in hand with high yields and hence the attempt to combine these aspects into viable soil conservation programs. One has to remember that farmers grow crops to make a profit. Maximum profits are achieved by lowering the cost per unit of production.

All production practices must be managed to the best ability of the farmer. He must use high quality seed, control weeds, insects and diseases, minimize cultivation activities, etc. In addition to these practices, a farmer must optimize his fertilizer program based on realistic yield goals for his farm. This means using the right kind of fertilizer, in the right amount, in the right place, at the right time. Fertilizers are supplemental sources of nutrients. Their use needs to be balanced with knowledge of nutrient cycling and soil sustainability for future production.

Farmers must become "researchers" on their own fields. They should experiment with various programs to determine which is best for them using their own management skills. Researchers have the challenge of developing fertilizer management practices for all soil types and climates. Research performed on University farms and by professional researchers on farmer's fields are extremely valuable. However, they do not necessarily relate directly to every farmer's fields. Soils have tremendous variability from one farm to another. Cultural practices vary markedly from one farmer to another. Even climatic factors can vary significantly over very short distances. All of these factors affect possible responses from fertilizer programs.

All of this means that the farm operator who survives in the 1990's and beyond is going to have to experiment a little on his own, keep accurate records, be flexible to government programs, world market price fluctuations and soil and water conservation needs.

It is never wise to change the program for an entire farm without trying out programs on a limited basis first. Yields vary from year to year with climate, insects, disease, etc. Unless comparisons are made under the same conditions, they have very little value. Farmers must become better managers. Fertilizer dealers and farmers must become more knowledgeable and environmentally conscious and researchers must help develop adequate technology transfer packages for their purposes. A tall order - but achievable.

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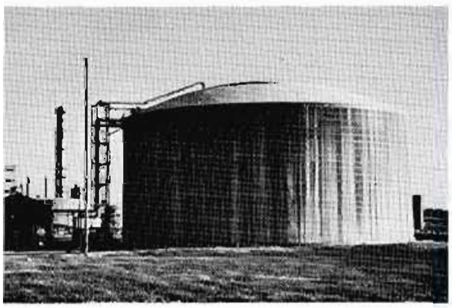

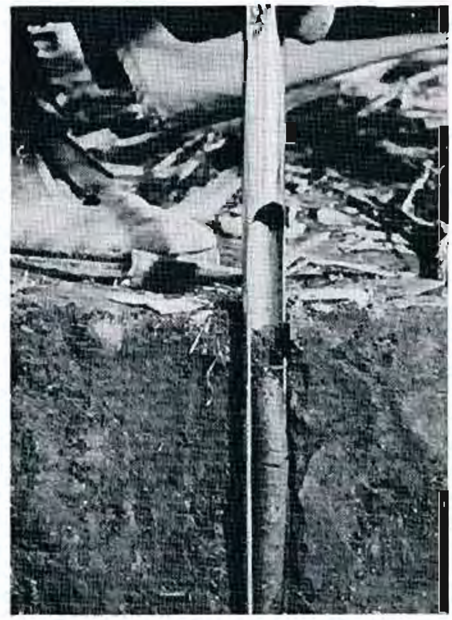

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