Economic and Agronomic Impacts of Varied Philosophies of Soil Testing[1]

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ABSTRACT

Philosophical differences exist in the interpretation and recommendations made from soil test values acquired by different organizations that provide advice to farmers on fertilizer use. It was the objective of this study to evaluate the economic and agronomic impacts of these varied philosophies with particular reference to concepts of cation ratio, nutrient maintenance, and nutrient sufficiency level. Field experiments were conducted during 1973–1980 on four major soils of Nebraska comparing yields of corn (*Zea mays* L.) grown with fertilizer treatments as recommended by five soil testing laboratories operating in the state. The 29 field comparisons revealed no real yield differences despite wide variation in number, rate, and cost of nutrients applied. Since soil test levels are increasing or at least holding steady with the "nutrient sufficiency" approach to soil testing, we find no economic or agronomic basis for the "balance" or "maintenance" concepts on these representative soils of the western Corn Belt. Not to be overlooked are environmental implications nor the waste of energy and resources from any approach responsible for excessive fertilizer use. It is recognized that reserves of available nutrients in the deep subsoils and underlying soil-forming materials in this region have a substantial bearing on soil test calibration and that different calibrations may exist with less favorable subsoil rooting conditions.

Additional index words: **Fertilizer efficiency, Nutrient maintenance, Cation ratio, Soil test calibration, Nutrient sufficiency.**

SOIL fertility research and associated laboratory studies over the past 30 years have established the efficacy of soil testing as a means for predicting the nutrient needs of crops to be grown. The procedure is generally recognized as the best available for diagnosing soil nutrient limitations before a crop is planted so that correction can be made in that year by appropriate fertilization. Although generally accepted as a viable practice, real philosophical differences exist on interpreting the tests. This results in radically different fertilizer recommendations being given to farmers with attendant erosion in credibility of soil testing.

Three major concepts are in use by the various organizations doing soil testing, viz., maintenance, cation saturation ratio, and sufficiency level. The maintenance concept implies that whatever the soil test level, a quantity of nutrient should be added to replace the amount expected to be removed by the crop. This "conservation" of a soil's nutrient supplying capacity has strong appeal but discounts the economic aspect to the farmer in those situations where the soil's delivery capacity of a given nutrient may be adequate for top yields for some years to come. Focus is primarily on NPK rather than the 13 soil-derived nutrients, all of which should receive equal consideration if the approach were truly to represent the maintenance concept.

The cation ratio concept probably originated from New Jersey work that projected an ideal soil as one with the following distribution of exchangeable cations: 65% Ca, 10% Mg, 5% K, and 20% H, therewith Ca:Mg of 6.5:1, Ca:K of 13:1 and Mg:K of 2:1 (2, 3). These required proportions would be expected to be quite different with soils of a different clay mineral type, e.g., those from Missouri with suggested optimum proportions of 75% Ca, 10% Mg, and 2.5 to 5% K (6). Many subsequent studies, however, have shown little relationship between crop yields and the above ratios of soil exchangeable cations; instead wide variations in those ratios have had no adverse effects on yields or crop quality (7, 8, 9). The literature indicates that field calibration of any of the cation ratios to yield response is tenuous at best.

The sufficiency level concept derives from studies that reveal no yield response to an applied nutrient above a certain soil test level. It has come from long-term calibration of soil tests with field yield response data establishing ranges of "response assured," "response likely," "response possible," and "response unlikely," otherwise expressed as very low, low, medium, and high nutrient level (11, 13). The sufficiency level concept is employed by most university laboratories involved with testing farmers' soil samples, whereas a combination of the cation ratio and maintenance concepts are in use by the majority of commercial laboratories. As a result, most university laboratories have come to be regarded as too conservative with their fertilizer recommendations.

There is added disagreement among soil testing laboratories concerning depth of soil that needs to be sampled for effective nutrient prescription purposes. Traditionally, the tillage layer of soil has received primary emphasis based on the predominance of roots in and nutrient uptake from that zone. The significance of subsoil nutrient reserves, however, is increasingly being recognized in soil test calibration research (10, 12, 15). These reserves are particularly important with the mobile elements like N, somewhat less for immobile nutrients such as P and Zn.

Ultimately, soil testing must serve not only economic and agronomic requirements but those of environmental scope as well. Examples exist around the country and the world of detrimental environmental effects from excessive nutrient applications, including unacceptable levels of nutrients in surface and ground waters and outright toxicity of certain elements in fruits and vegetables (4). Reliable soil testing, especially as it measures the rooting profile and not just surface soil levels, can be the most effective means of keeping this problem in check. Accordingly, the basic objectives of this study were to determine how well the economic, agronomic, and environmental interests of agriculture were being served by soil testing in Nebraska and to acquire further assurance of the adequacy of university recommendations for satisfying those interests.

MATERIALS AND METHODS

Four field locations were selected for conducting this study during 1973–1980: the Mead Field Laboratory; the South Central Station; the North Platte Station; and the Northeast Station. Corn was grown continuously on the plots, allowing fertility objectives of the various labs to be

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Table 1. Description of experimental sites.

Site	Soil type	Yield goal	Irrigation	Years
		kg/ha		
Mead Lab	Sharpsburg Sicl	10,700	Yes	1973-80
North Platte	Cozad Si l	10,700	Yes	1974-80
South Central	Hastings Si l	10,700	Yes	1974-75
		12,500	Yes	1976-79†
Northeast	Moody Si l	5,700	No	1974-80

† Soybeans grown in 1980 without further treatment for evaluating residual fertilizer effects.

achieved over several years' time with yield goals as specified in Table 1. The Sharpsburg (Typic Argiudoll), Hastings (Udic Argiustoll), and Moody (Udic Haplustoll) soils are three of the most extensive cultivated soil series in the state while Cozad (Fluventic Haplustoll) occupies a large area of central Platte Valley benchlands.

A representative soil sample was collected from the entire experimental area of each location in the first year, was thoroughly mixed and then divided into five subsamples. One sample was mailed to the University Soil Testing Laboratory (Lab E) and one to each of four commercial laboratories (Labs A, B, C, D) providing most of the soil testing service to Nebraska farmers. After the first year each laboratory received a soil sample composited from all the replicated plots to which fertilizer had been applied according to that laboratory's recommendations in the prior year(s). In most cases N recommendations by Lab E were made from profile samples taken to a depth of at least 60 cm with all laboratories having corresponding opportunity. The manner of handling and mailing the sample was such that no laboratory, including the University's, would know that this was not a farmer's sample. All nutrients suggested by a laboratory were assumed to be needed and were broadcast and incorporated prior to planting. A high yielding corn hybrid adapted to the respective area was planted near the accepted optimum planting date in 76 cm rows with four to six replications and cultural practices of irrigation, cultivation, and pest control applied as required for the site. Yield estimates were derived by hand harvesting ears from 12 to 15 m of row at maturity, shelling, and correcting to 15½% moisture. Fertilizer costs in the data figures were derived from statewide average retail costs for nutrients during the spring peak consumption period for the years involved.

Following harvest of the 1980 crop, soil samples from 0 to 15 cm, 15 to 30 cm, and by 30 cm increments through 180 cm were taken of all plots at each location. Measurements were made on these profile samples of NO_3-N by steam distillation, organic matter by Walkley-Black wet digestion, pH by glass electrode on 2½:1 water: soil suspension, soil P by Bray and Kurtz no. 1 extraction, and exchangeable K by flame photometry following NH_4OAc extraction. Determinations were also made on surface soil samples of B by hot water extraction; CEC, Ca and Mg by NH_4OAc extraction; Mn, Cu, and Fe by DTPA extraction and Zn by 0.1 *N* HCl extraction, all measured by atomic absorption spectroscopy; and SO_4-S by $Ca(H_2PO_4)_2$ extraction and turbidimetric analysis. The only profile data presented are those for NO_3-N in some of the figures since differences in status of other soil nutrients among lab plots were not significant below the 0 to 30 cm depth.

RESULTS AND DISCUSSION

Figure 1 depicts some of the more important chemical characteristics for the 180 cm profile of the four soils on which the study was conducted. The Sharpsburg and Hastings soils are slightly acid to neutral in reaction throughout, with P depletion of the B horizon but with large available P reserves in the deep subsoil.

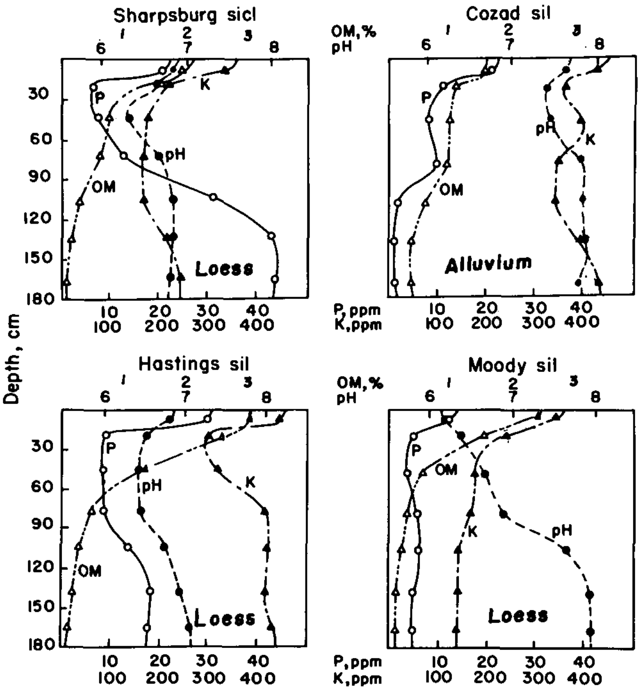

Fig. 1. Chemical characteristics of the 180-cm profile of the control soil at the four experimental sites after the 1980 harvest.

The higher subsoil pH of Moody and Cozad from free lime presence is associated with much lower soil P levels. Organic matter contents of around 3% in the surface soils of Hastings and Moody are distinctly higher than in the Sharpsburg (eroded) and Cozad, while exchangeable K is very high in all soils. These profile characteristics of soils from the western Corn Belt present an entirely different soil fertility medium to a crop than exists in eastern soil regions with strongly acid subsoils or those western soils that are calcareous throughout the profile.

Average annual fertilizer applications as recommended by the various laboratories along with average yields and fertilizer costs for the years of the study are presented in Fig. 2, 3, 4, and 5. Yield goals were generally met throughout the course of the study at all locations despite the vagaries of climate and pest impact. No significant differences in yield occurred from treatments advocated by the different laboratories for any location except the South Central Station where results for Lab C were less than those from other laboratories. There were, however, wide differences in the kinds and amounts of nutrients recommended with resulting large disparity in costs for the fertilizer treatments. Accordingly, from the economic standpoint alone, there is no question of the superiority of the more conservative fertilizer recommendations provided by Lab E.

A modest reduction in soil pH has accompanied the N applied to all lab plots with only small differences attributable to the varied fertilizer programs to date, Lab E plots averaging about 0.2 pH unit higher in the surface soil than other lab plots (Table 2). It is evident from the data, however, that long continued application of the larger amounts of N, P, and S advocated by some of the commercial labs would accentuate the

Table 2. Soil test values on the surface 15 cm after the 1980 crop season along with values for the experimental area at initiation of the study.

	Nutrient									
Location & Laboratory	NO_3-N	B&K#1 P	Exch. K	SO_4-S	0.1 *N* HCl Zn	DTPA Fe	DTPA MN	DTPA Cu	Hot H_2O B	pH
	ppm									
Mead										
A	16	37	349	17	11.8	26	1.1	0.7	6.2	
B	15	26	321	23	5.7	26	23	0.9	0.5	6.2
C	17	21	320	18	10.4	27	23	1.2	0.8	6.3
D	12	28	332	15	6.7	27	24	0.9	0.6	6.2
E	20	20	331	10	6.8	22	21	0.9	0.5	6.4
Control (1980)	4	8	328	10	5.1	21	6	0.7	0.6	6.8
Experimental area (1973)	–	10	267	–	6.0	–	–	–	–	7.0
North Platte										
A	18	62	490	15	7.6	11	11	0.4	0.9	6.8
B	17	36	438	15	12.3	8	8	0.5	0.6	7.1
C	15	30	415	26	13.6	9	8	0.9	0.8	7.0
D	20	77	438	19	5.2	11	9	0.5	0.9	6.9
E	22	28	460	20	6.9	9	8	0.4	0.7	7.1
Control (1980)	7	20	406	18	3.9	5	7	0.4	0.6	7.6
Experimental area (1974)	–	21	417	–	4.5	–	–	–	–	7.1
South Central Station†										
A	6	70	495	16	11.3	41	16	1.4	1.1	6.5
B	8	34	493	19	10.3	39	17	1.1	1.5	6.6
C	8	55	495	14	29.4	28	15	1.6	0.7	7.0
D	8	59	431	17	7.3	34	19	1.1	1.0	6.7
E	9	33	431	22	7.5	22	13	0.9	0.7	7.1
Control (1980)	7	28	445	21	4.9	25	16	0.8	0.6	6.8
Experimental area (1974)	–	21	467	15	3.5	–	–	–	0.3	6.3
Northeast Station										
A	5	16	343	6	7.0	41	36	1.3	0.7	6.0
B	6	15	280	5	6.0	39	34	1.3	0.6	6.0
C	9	12	316	10	10.0	41	38	1.4	1.0	5.9
D	12	16	353	4	5.6	40	37	1.3	0.8	5.9
E	10	15	286	3	6.0	41	36	1.2	0.9	6.1
Control (1980)	3	12	325	3	5.0	33	32	1.1	0.9	6.2
Experimental area (1974)	–	18	307	–	5.4	–	–	–	–	6.1

† Soil was limed differentially by lab recommendations in 1976.

problem of soil acidity even in the three irrigated situations where appreciable amounts of Ca and Mg (60 to 75 ppm of the two) are supplied by the irrigation water. Pertinent to S fertilizer recommendations is the fact that irrigation water at the Mead, South Central, and North Platte locations contains from 10 to 30 ppm SO_4-S, more than enough with nominal irrigation to supply all possible crop S requirements.

Substantial differences in status of several soil nutrient elements have developed from the varied fertilizer treatments (Fig. 6, 7, 8, and 9). Note in Fig. 6 that surface soil P, Zn, and S levels have been more than doubled by some of the laboratories' treatments reaching concentrations far in excess of the University-recognized sufficiency levels expressed on the figure. After the 8-year period all lab treatments have left the Sharpsburg soil with sufficient residual NO_3-N for a near optimum yield without further N addition for the 1981 crop (12). We can only conjecture as to the future hazards in trace element nutrition from the soil P and Zn levels developing with some of the laboratories' recommended treatments.

The Cozad soil is also evidencing a substantial buildup of soil P and Zn as well as Cu with some of the programs (Fig. 7). There would appear to be no logical basis for further P and Zn recommendations when levels four to five times that of known sufficiency have been reached, and again apprehension must be expressed concerning eventual impact in this case of excessive P, Zn, and Cu on Fe and other trace element nutrition.

Levels of P, Zn, and Cu have been multiplied by some of the commercial programs on the Hastings soil of the South Central Station (Fig. 8). During the 6-year period represented, 36 kg/ha of Zn has been applied to the plots of Lab C raising soil Zn to an exorbitantly high level. Likewise, concern can be expressed about the increasing B concentration with some of the plots considering that 1.5 ppm B or more in the saturation extract of soil may be unsafe for the production of most crops (16). Precise levels where Cu toxicity will be manifest are not predictable, but disregarding the issue can bring on problems analogous to those of "vine producing soils" in southern France where Cu toxicity has been the No. 1 agronomic problem, the result of long-term Bordeaux mixture spraying for pest control.

The Moody soil of the Northeast Station has acquired unnecessarily high levels of Zn, S, and NO_3-N from some of the commercial programs as reported in Fig. 9. The question mark on the figure concerning sufficiency level of S attributes to the need for more than a surface soil value in predicting S fertilizer requirement. The residual of 300 kg/ha of NO_3-N in the 180-cm profile is enough for more than 2 years of the projected annual yield of 5,700 kg/ha in the case of Lab D, provided the NO_3-N does not leach away to the ground water with attendant environmental implications.

As for the usefulness of cation saturation ratios in predicting need for K and Mg, it will be noted that K was recommended by all commercial laboratories

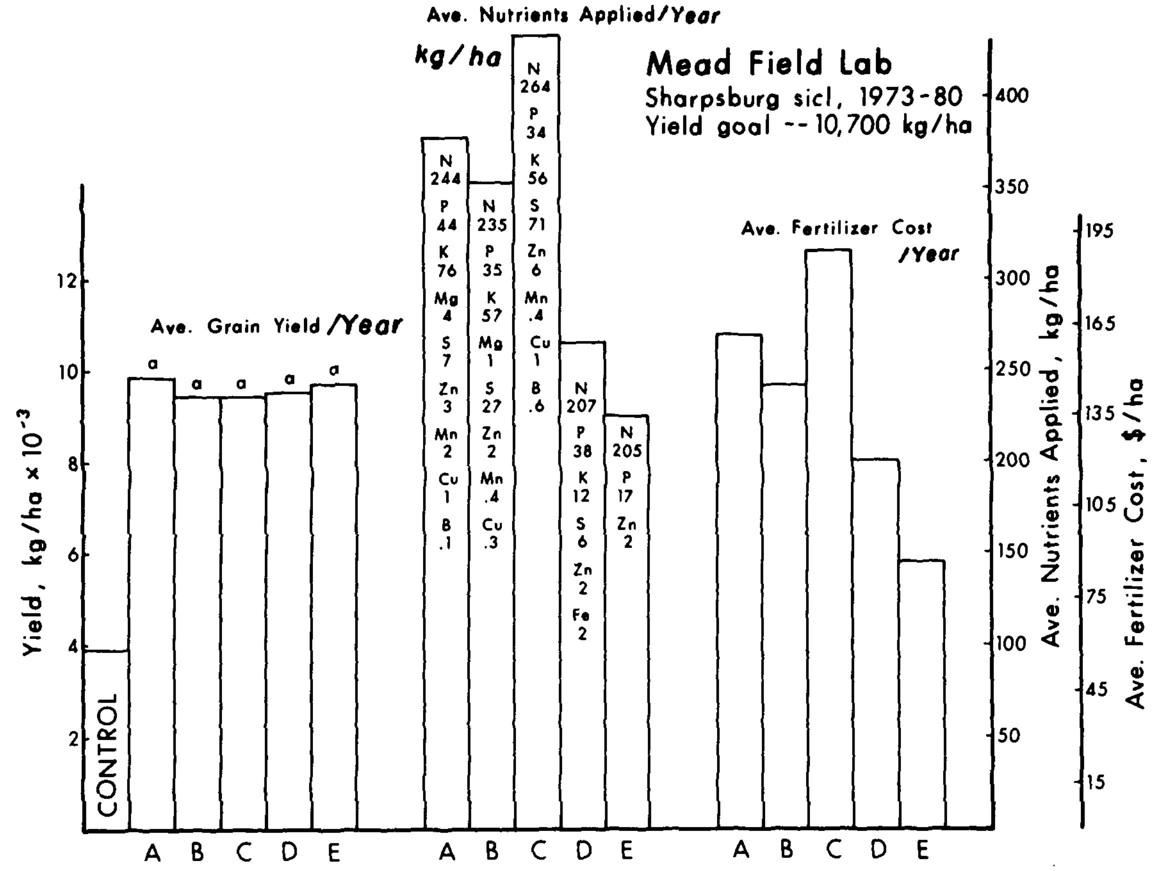

Fig. 2. Average annual grain yields, nutrients applied, and fertilizer costs for irrigated corn produced on Sharpsburg sicl. Mead Field Laboratory, with fertilizer programs recommended by labs A, B, C, D and E; 1973–80.

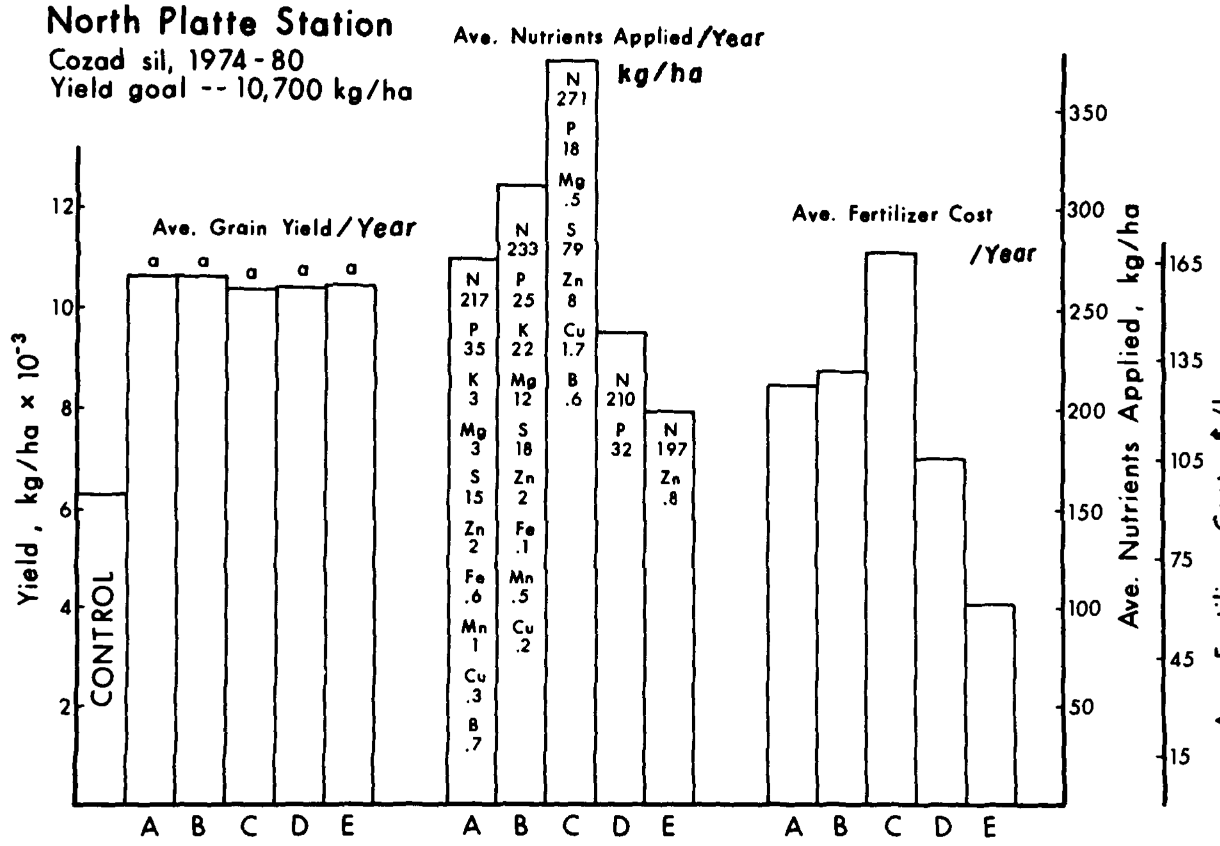

Fig. 3. Average annual grain yields, nutrients applied, and fertilizer costs for irrigated corn produced on Cozad sil, North Platte Station, with fertilizer programs recommended by labs A, B, C, D and E; 1974–80.

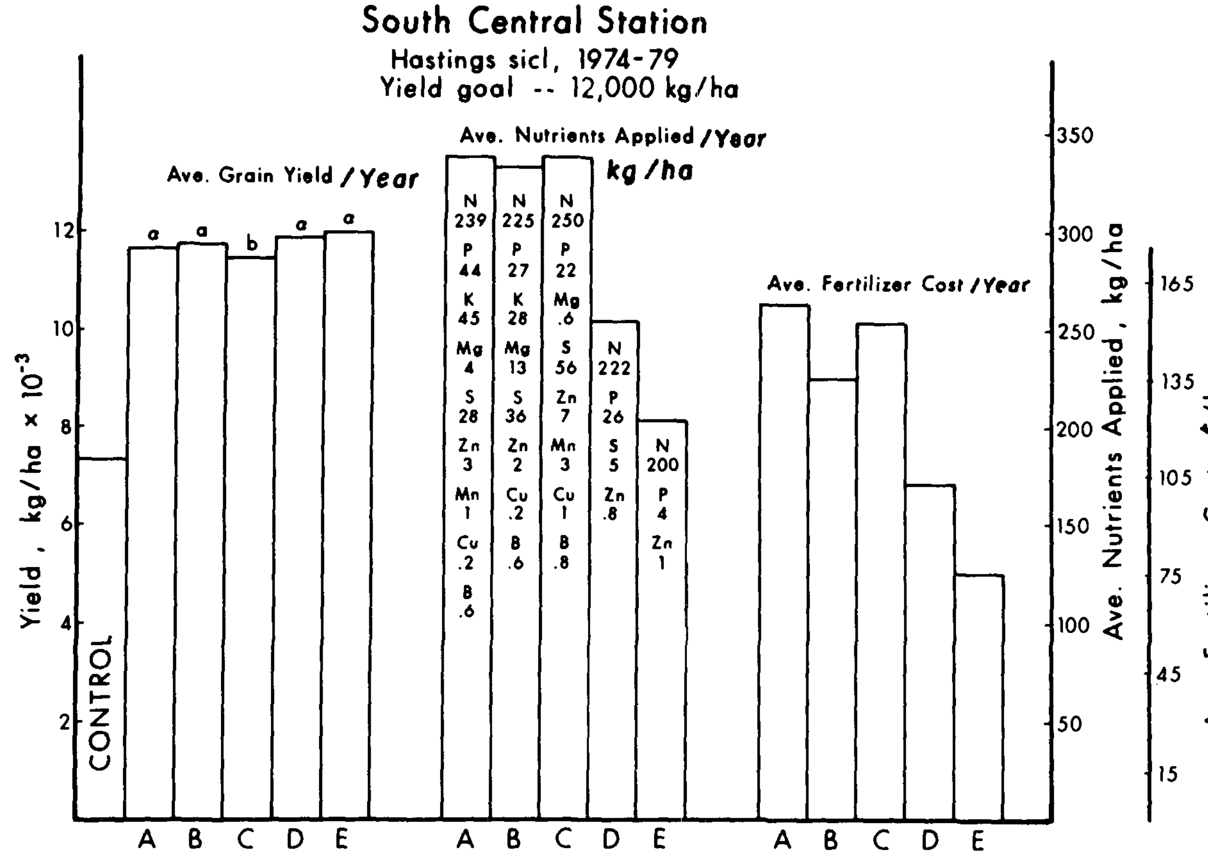

Fig. 4. Average annual grain yields, nutrients applied and fertilizer costs for irrigated corn produced on Hastings sil, with fertilizer programs recommended by labs A, B, C, D and E, 1974–79. (Yield goal of 10,700 kg/ha set for the first 2 years, raised to 12,500 kg during the last 4 years or average of 12,000 kg).

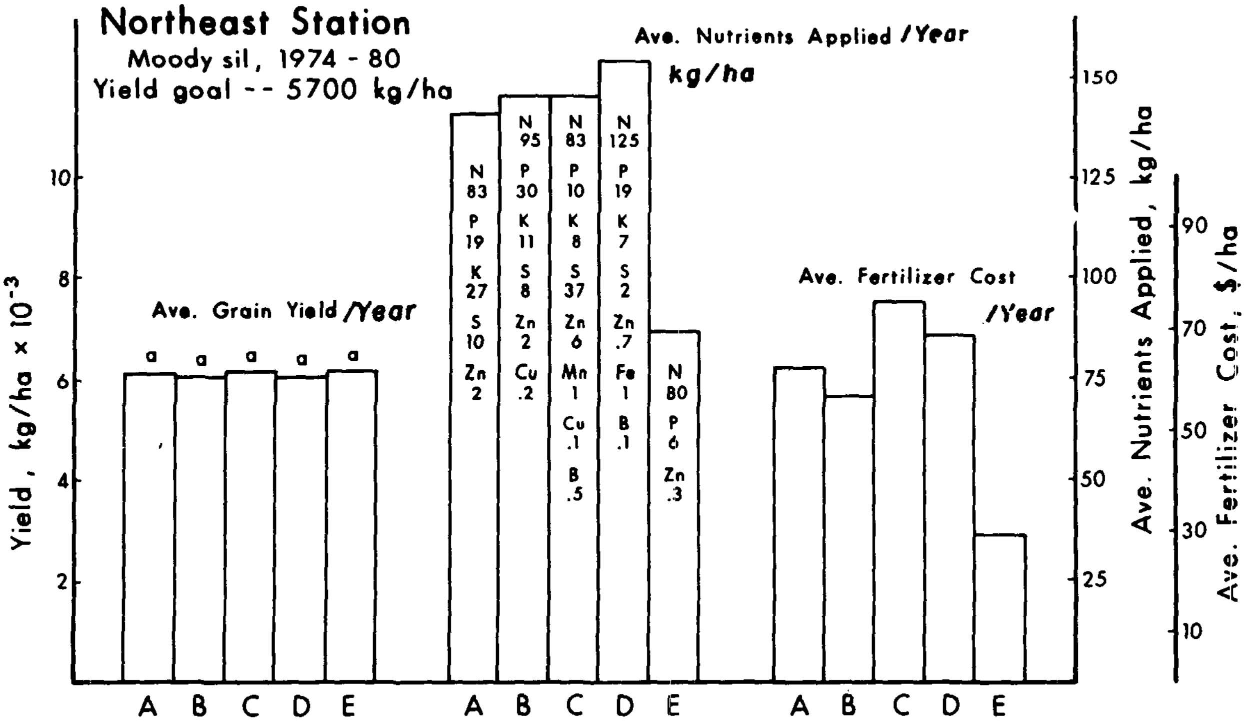

Fig. 5. Average annual grain yields, nutrients applied and fertilizer costs for corn produced on Moody sil, with fertilizer programs recommended by labs A, B, C, D and E, 1974–80.

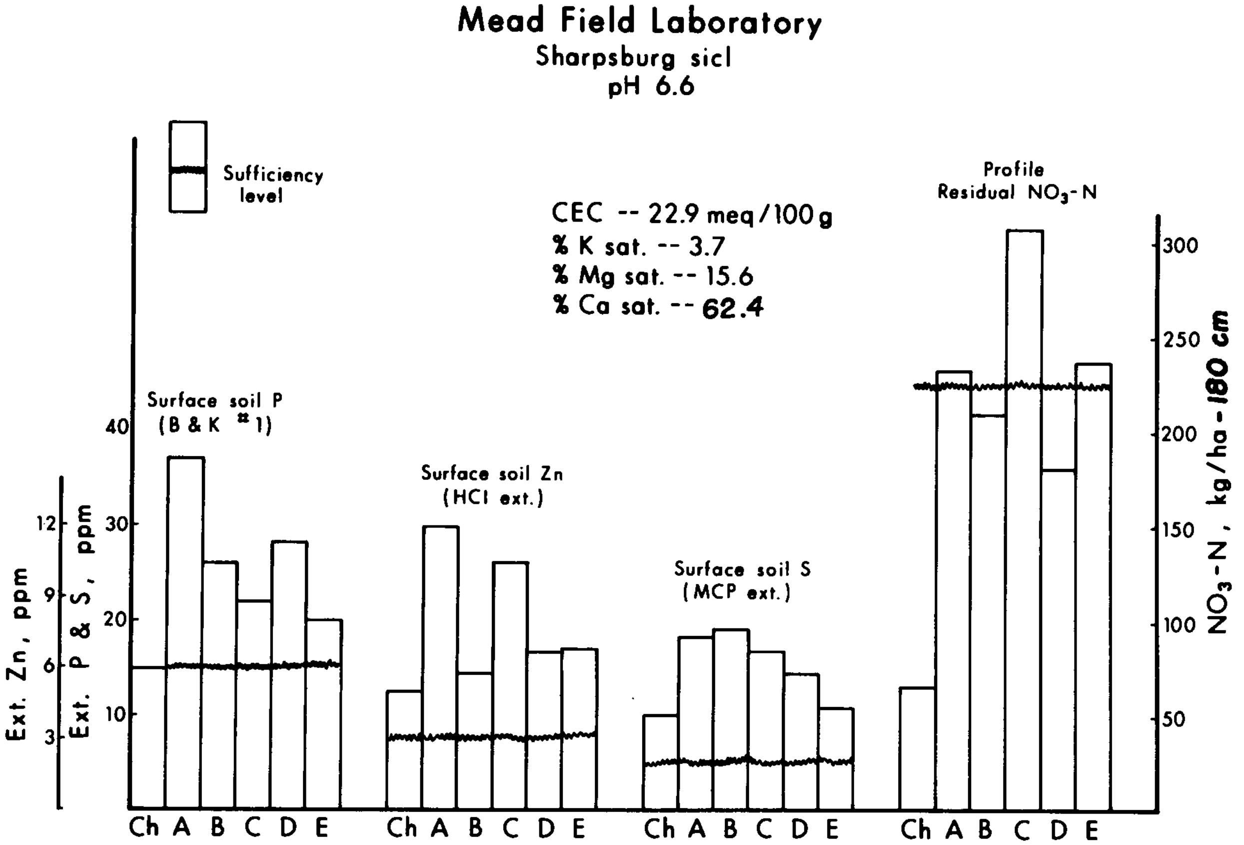

Fig. 6. Changes in nutrient status of Sharpsburg sicl surface soil and profile NO_3-N effected by the varied fertilizer programs of labs A, B, C, D and E during the 8-year study period (Cation capacity values obtained from control plots; B & K = Bray & Kurtz; ext. = extractable).

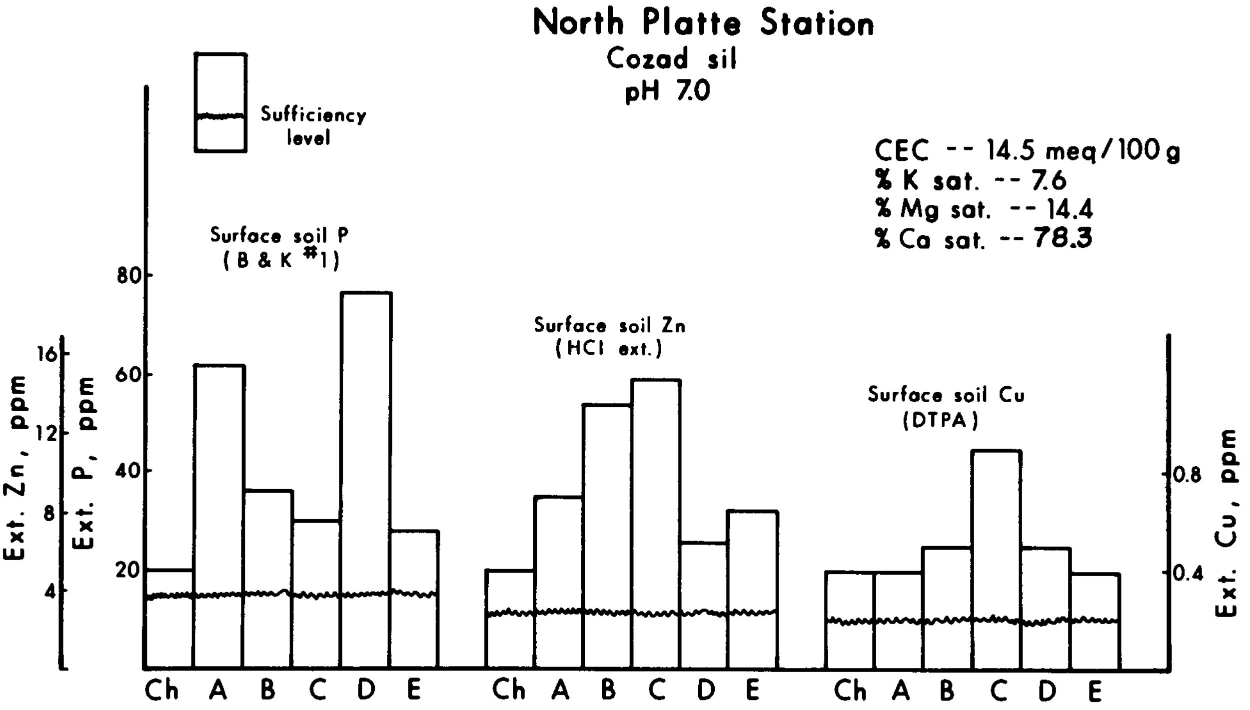

Fig. 7. Changes in nutrient status of Cozad sil surface soil effected by the varied fertilizer programs of labs A, B, C, D and E during the 7-year study period (Cation capacity values obtained from control plots; B & K = Bray & Kurtz; ext. = extractable).

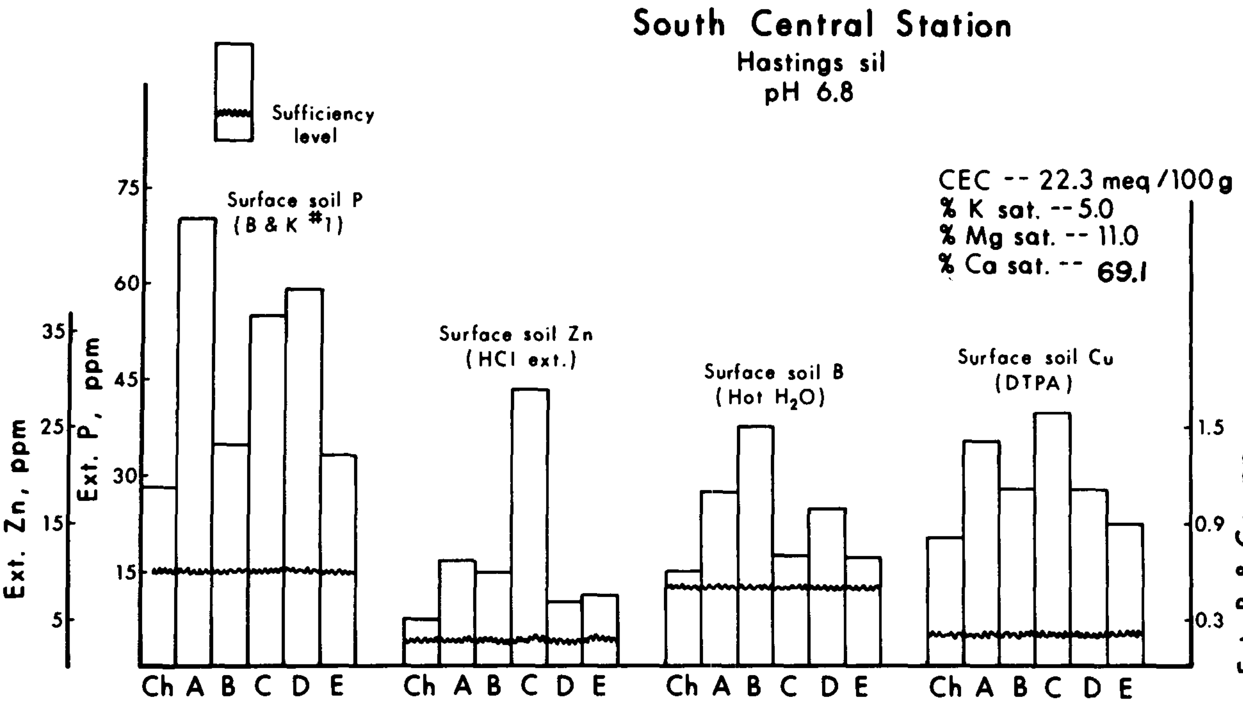

Fig. 8. Changes in nutrient status of Hastings sil surface soil effected by the varied fertilizer programs of labs A, B, C, D and E during the 6-year period (Cation capacity values obtained from control plots; B & K = Bray & Kurtz; ext. = extractable).

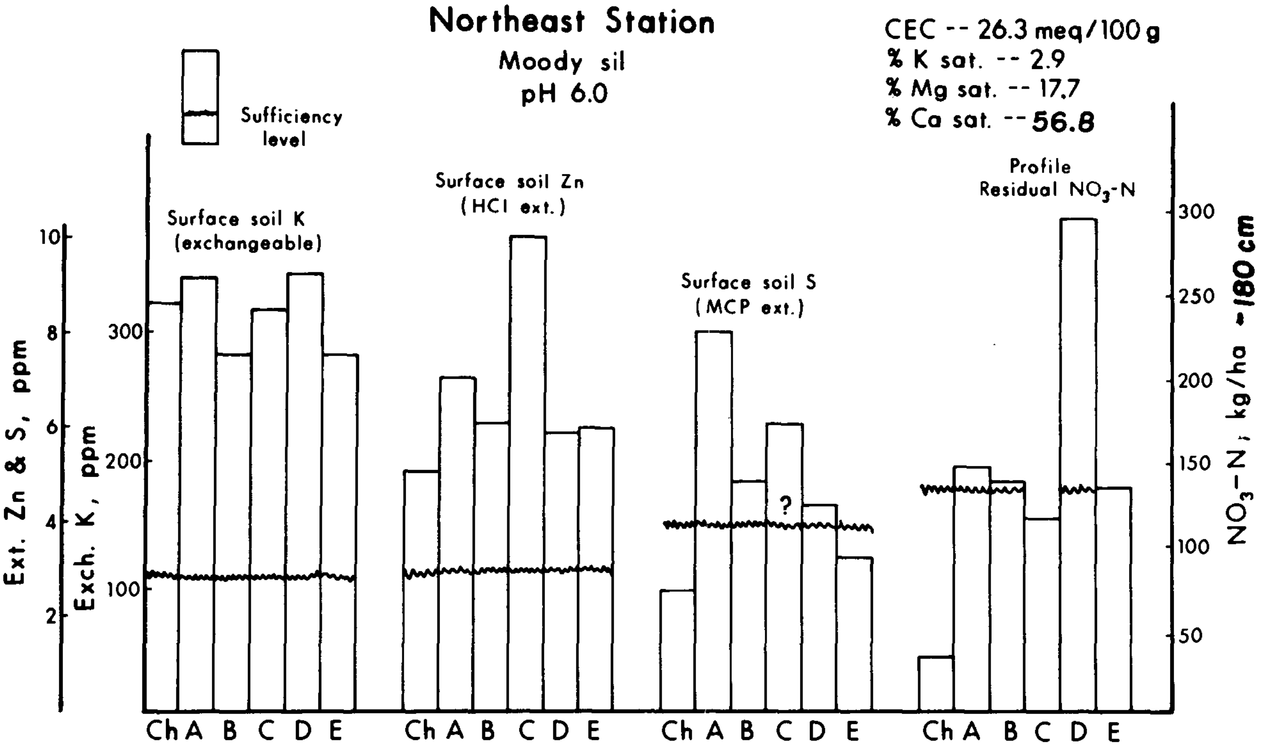

Fig. 9. Changes in nutrient status of Moody sil surface soil and profile NO_3-N effected by the varied fertilizer programs of labs A, B, C, D and E during the 7-year period (Cation capacity values obtained from control plots. The ? on sufficiency level for S prompted by the need for profile and not just surface soil test values for S; ext. = extractable; exch. = exchangeable.

and Mg·by Labs A and B for the Sharpsburg soil without influencing yields (Fig. 2). The Ca/K ratio of the control soil at this site was 13.1/1, the Ca/Mg ratio 3.1/1, and the Mg/K ratio 4.2/1, suggesting the possibility of K shortage or Mg excess by the cation saturation ratio concept (3, 6). Not presented in Fig. 3 is the additional fact that soil exchangeable K has not changed perceptibly over the 8-year period despite varied K treatments (Table 2). Labs A and B similarly advocated appreciable K and Mg treatments for the Cozad (Fig. 3) and Hastings (Fig. 4) soils, whether for maintenance or cation balance purposes, without influencing yield with soil Ca/K ratio of 8/1, Ca/Mg of 4.2/1, and Mg/K of 1.9/1 in the former soil and Ca/K of 10.5/1, Ca/Mg of 4.8/1, and Mg/K of 2.2/1 in the latter. Again, soil K was not perceptibly changed by treatment throughout the period of study at the very high K levels of the soils involved (Table 2). No Mg was recommended for the Moody soil (Fig. 5), but K was advocated by all but Lab E with Ca/K of 16/1, Ca/Mg of 2.6/1, and Mg/K of 6/1 and with no significant effect on yields or change in soil test K after the 7-year period. It is apparent that cation ratio was of little relevance in expressing need for the elements K and Mg, although the presence of large quantities of both throughout the entire 180 cm profile of all soils may have been a conditioning factor. Earlier studies have indicated that yield response to K in this region is quite unlikely when soil exchangeable K levels are high throughout the rooting profile (5). This high K has been true even with quite sandy soils having illite as an important component of the clay and K feldspars in the silt and clay fractions because of rapid K release from nonexchangeable form in the clay lattice and from primary mineral weathering (1, 14).

Is there any indication that the sufficiency level concept is causing a depletion in available soil nutrients that will eventually be responsible for lowered productivity? The summary of surface soil test data from all locations and plots in Table 2 indicates otherwise as comparison is made against values for Lab E and control samples. There would seem to be no cause for concern so long as continuous surveillance maintains test values above the sufficiency level.

CONCLUSIONS

These Nebraska results make it quite clear that cation balance in soil is not an essential consideration in estimating crop nutrient needs for the yields obtained and soil conditions of this study. Neither is the maintenance concept of fertilizer recommendations economically valid with soils already containing more than enough of the nutrient(s) under consideration for optimum yields. The nutrient sufficiency approach to soil testing, when adequately calibrated, promises the surest method of achieving most economic yields while conserving non-renewable resources and preserving environmental integrity. The results additionally evidence the need for subsoil nutrient measurements in providing most reliable fertilizer prescriptions.

This paper may serve as response to the often-heard complaints that universities are too conservative in their fertilizer recommendations. The fact that they are advocating use of only those materials needed for most economic production, "conservative" would seem the correct approach to conserving energy and limited natural resources while preserving an acceptable environment. The growth in inorganic fertilizer use has contributed more than any other factor to the vast increase in agricultural productivity of the USA since World War II. It was by no means the intent of this investigation to downgrade this all-important requisite, but rather one of enhancing efficiency in fertilizer use to the benefit of farmer and country.

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