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SOIL ANALYSES--ARE THEY NEEDED FOR NURSERY DATA INTERPRETATION

R. A. Olson, et al

Nebraska University

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Soil fertility exerts a major role on the yield and quality of winter wheat wherever produced. Although deficiencies of N, P and K are most likely to limit production in wheat-producing regions of the world, shortages of other elements are being increasingly recognized with introduction of varieties of higher yield potential and with application of improved overall soil-crop management systems. With the exception of a few elements like Fe and Mn, authenticated methods have been developed for soil nutrient evaluation by soil testing which should prove invaluable to the researcher responsible for varietal evaluation in wheat nurseries. Not only is knowledge of nutrient level needed for preventing deficiency, but this information is essential for preventing excesses that may be responsible for yield reduction due to toxicity or unfavorable interaction with another essential element of plant nutrition. Nurseries should be established under optimum fertility conditions as it is important for plant breeders to be certain tha varietal differences in yield at a given location are not reflections of genotype selectivity in nutrient uptake.

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SOIL ANALYSES--ARE THEY NEEDED FOR NURSERY DATA INTERPRETATION?

by

R. A. Olson, D. H. Sander, and A. F. Dreier
United States

Introduction

Demonstrations and trials of fertilizer use on farmers' fields can be quite sufficient to give a general picture of nutrient needs in an area new to fertilizer use, especially in the less exotic soil regions of the world where N, P, and/or K is/are the likely deficient nutrient(s). With refinements in production capabilities, however, including the introduction of modern, high-yielding varieties in place of traditional varieties, and especially as differential management results in nutrient buildup in some soils and not in others, soil analyses become increasingly essential. Not only are they useful for predicting nutrient deficiency and the most economic rates of fertilizer application for profit, but they can forecast the imminence of excessive buildup of a certain element that may be capable of inducing the deficiency of a competitive nutrient if not of generating a toxic condition. Eventually, with widespread and intensive fertilizer use, they become indispensable for assuring that applied nutrients do not become environmental pollutants.

With the advent of inexpensive inorganic fertilizers since 1945, it has become very apparent that plant breeding efforts must be directed toward optimum fertility conditions. The great success of the CIMMYT and IRRI programs has come about through recognition of the need for integrating the additional factors of effective water management, pest control, and appropriate fertility treatment for validating the 'miracle' varieties (1).

Nutrient Role in Wheat Production

Yield Effects. Availability of plant nutrients plays a determinate role on the yield and quality of wheat wherever produced. A recent world-wide trend of increasing average annual yield is apparent as agricultural statistics are studied, a growth heavily hinged to increasing fertilizer consumption (2). It is not the fundamental purpose of this paper to focus on response of wheat to fertilizers *per se*, since this has been the topic of previous presentations (5, 11). Certainly, we cannot overstress the need for adequately supplying the thirteen known essential nutrients normally absorbed through the root system by the crop. Limitation of any one of these will be yield inhibitive until correction of that deficiency has been accomplished. Thereafter, with adequate genetic and climatic potential, the next most limiting nutrient will represent the yield barrier, as was detailed by Liebig in his Law of the Minimum.

Although N, P, and K are the nutrients most extensively deficient for optimum production, certain soils in most of the countries here represented are deficient in Ca, Mg or S. Note in Table 1 that a maximum expression of yield and protein content of wheat with a nominal rate of N application was obtained only as the

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Sharpsburg soil with plentiful available P and pH 5.6 had been limed in this 3-year study. The Ca and Mg base limitation with possible Al and Mn toxicity will become more and more evident in noncalcareous soils with increasing use of fertilizer N as time passes. Sulfur limitation becomes increasingly probable the more humid the climatic environment and may exist in subhumid regions with soils of low clay and organic matter contents.

There is increasing recent evidence as well of local deficiencies in one or more of the elements Fe, Zn, Mn, Cu, B and Mo. These shortages have been accentuated by the introduction of improved varieties with greater yield potentials and by the decreasing dependence on animal manures as the sole fertilizer treatment by substitution of high analysis inorganic fertilizers.

Accepted that adequate nutrients are essential to efficient wheat production, it is almost equally mandatory that there be no appreciable excess in nutrient availability. Care must be exercised in the use of most of the trace elements as fertilizer by reason of toxicity potentials. Perhaps most problems in respect of excess, however, have been experienced with N. An overabundance of N will commonly cause excessive vegetative growth in most conventional wheat varieties of the drier regions with resulting tall, weak-stemmed plants that readily lodge. Excepted are some of the recently developed varieties with especially short and stiff straw. Too much N will also delay flowering, particularly where P availability is borderline or deficient, which can be deleterious to yield with a short growing season or if severe moisture stress develops.

Real differences are known to exist in the nutrient requirements of different wheat varieties because of varied yield potential and composition. It has also been demonstrated that differential Al toxicity effects exist with different wheat varieties grown on acid soils where the residual acidity is primarily a reflection of exchangeable Al (4). Differences in both respects are great enough that wheat breeders have been encouraged to develop varieties not only responsive to high nutrient availability but also resistant to toxicities that exist in specified soil regions, correction of the latter of which could well be more difficult and expensive than developing a tolerant variety.

Table 1. Yields of wheat and N uptake as influenced by liming and rate of fertilizer N applied on Sharpsburg si.c.l. (pH 5.6), Mead Field Laboratory, Nebraska, 1965-67.

N applied[1]	Grain yield		Protein content		Straw yield		Total N uptake	
	No lime	Lime[2]	No lime	Lime	No lime	Lime	No lime	Lime
kg/ha	kg/ha	kg/ha	%	%	kg/ha	kg/ha	kg/ha	kg/ha
0	2228	2363	11.6	12.6	3319	3341	51	57
Topdressed N after seeding								
28	2633	2835	11.9	12.5	3938	4050	66	73
56	2970	2970	12.8	13.1	4478	4388	81	84
N drilled 2.5 cm to side of seed row								
28	2700	2903	11.8	12.4	4219	4343	65	74
56	2970	3105	12.3	12.9	4680	4725	80	87

[1]Yield and uptake data are averages obtained with four NP carriers with P levels equalized by CSP.

[2]Limed plots received 25 tons lime/ha, bringing pH up to 7.5.

Protein Effects. A relatively high protein content has distinguished wheat as one of the higher quality foods traditionally consumed by man. It is a trait that is appreciably influenced by crop yield obtained and by the amount of N available to the crop. With a given variety and location and N limiting, yield and protein content are inversely related due to dilution, as evidenced in Fig. 1. Yields for each of the N treatment levels increased with increasing moisture availability in this experiment (0, 7, 15 and 21 cm irrigation water applied before planting in each of three years) at the expense of protein content of the grain. It is also apparent in Fig. 1 that both grain yield and protein percentage benefited from increased rate of N application.

Not only are protein effects from applied N very much dependent on water available to the crop, but residual N in the soil has a pronounced influence. Nebraska studies during the period 1965-1967 indicated that with high residual NO_3-N sites, non-responsive in respect of yield, the primary effect of applied N was to increase protein content (Fig. 2). With low residual NO_3-N in the 180-cm profile, however, the major effect of applied N was to increase yield with minimal effects on protein within the range of N rates employed. Correspondingly, yield increases from other nutrients usually caused decreases in protein from the dilution of a given quantity of N in the crop imposed by the higher yield.

Earlier papers in this conference have dwelt on the substantial differences in protein that may exist among varieties at a given location. It should be noted additionally that varied levels of applied N as well as other environmental factors can have greater impact on protein content than varietal effects among varieties yielding at a common level. Whereas the difference in average protein content among 19 varieties in 7 field tests of 1971 in Nebraska was only 1.6 percent, averages for all varieties among locations varied from 9.1 to 13.4 percent. Wheat protein thus varied more from location effects than from varietal effects in that year, as has been observed in previous years (9).

Much of the location variability can be explained in terms of moisture availability and fertility. An additional factor, however, is that of air temperature in the period shortly before maturity, with increasing temperature causing a shriveling of grain and consequent increased protein percentage. Where the four factors of NO_3-N in the soil profile to 1.5 m, precipitation during a 15-day period 40-55 days before maturity, available water to 1.5 m at seeding, and maximum air temperature for a 5-day period 15-20 days before maturity were combined in multiple correlation with protein content in a Nebraska-Colorado study, 96 percent of the variability in protein could be accounted for (8).

Response to Residual Fertility. Of utmost significance is the fact that the wheat crop responds to residual fertility as well as currently applied fertilizer nutrients. Recognition of this fact is essential for deriving efficient response to applied nutrient and for controlling potential pollution from fertilizer.

Figure 3 demonstrates the need for evaluating residual mineral N in soil for commercial wheat production as well as nursery plot evaluation of breeding stock. The wheat in this figure produced on continuously cropped land with mean annual rainfall ranging between 58-64 cm, evidenced little or no response to applied N when residual NO_3-N exceeded 90 kg/ha in the 180-cm soil profile. The growth response curve was still decidedly on the upgrade with 67 kg fertilizer N/ha applied for those experiments where residual NO_3-N was less than 45 kg/ha.

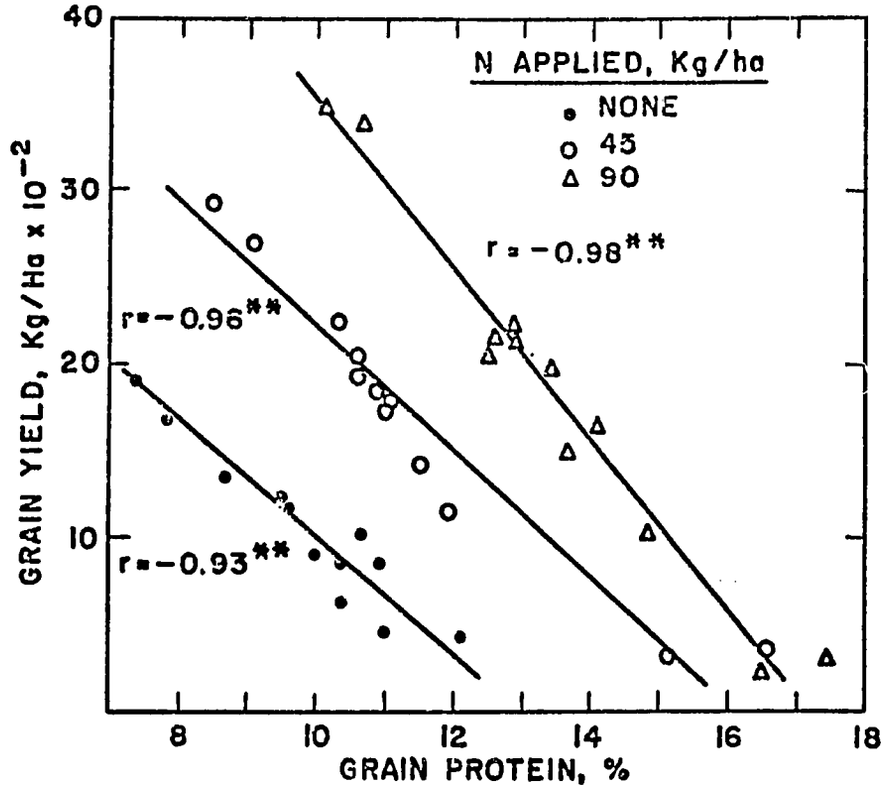

Fig. 1. Relation between grain yield and protein content of Cheyenne hard red winter wheat at North Platte, Nebraska, 1954-56 (9).

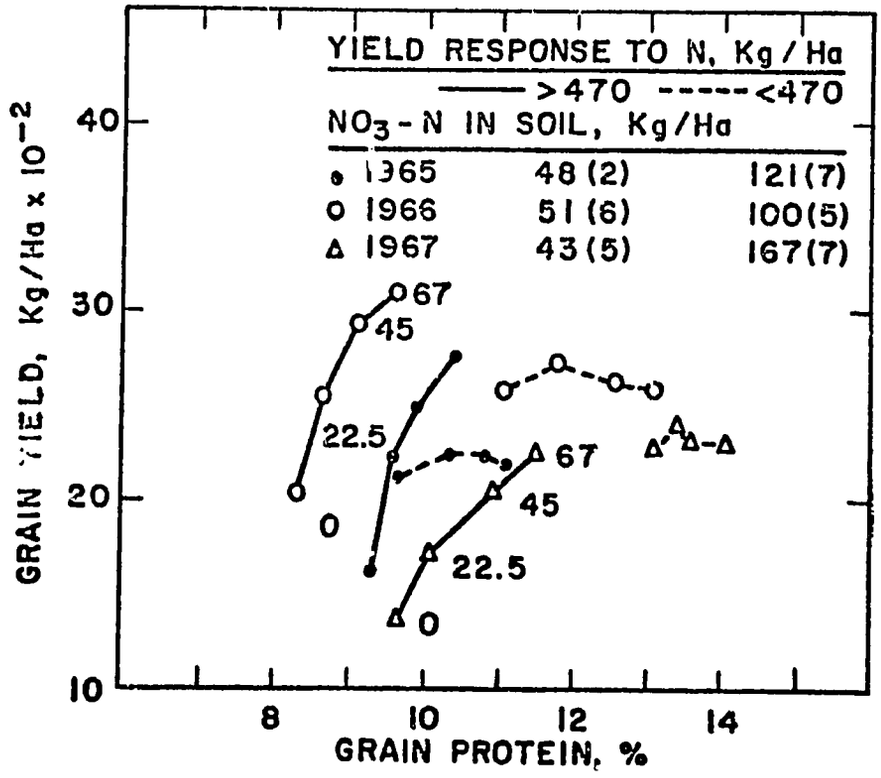

Fig. 2. Relation between grain yield and protein content of winter wheat as influenced by residual NO3-N in the soil and applied N (0, 22.5, 45 and 67 represent rate of applied N) 32 experiments in Nebraska, 1965-67.

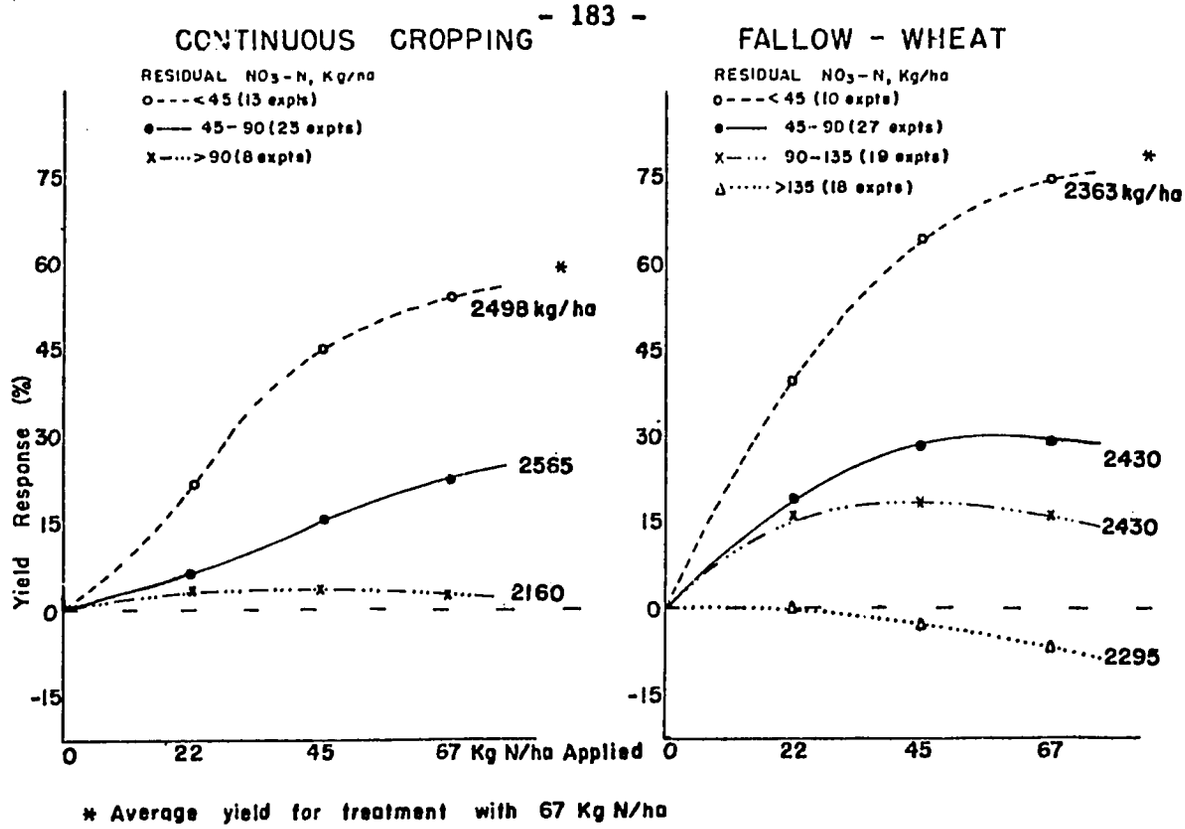

Fig. 3. Yield response of hard red winter wheat to increasing rate of applied N as influenced by residual mineral N in the 180 cm soil profile at planting time in 118 Nebraska field experiments of 1962-68.

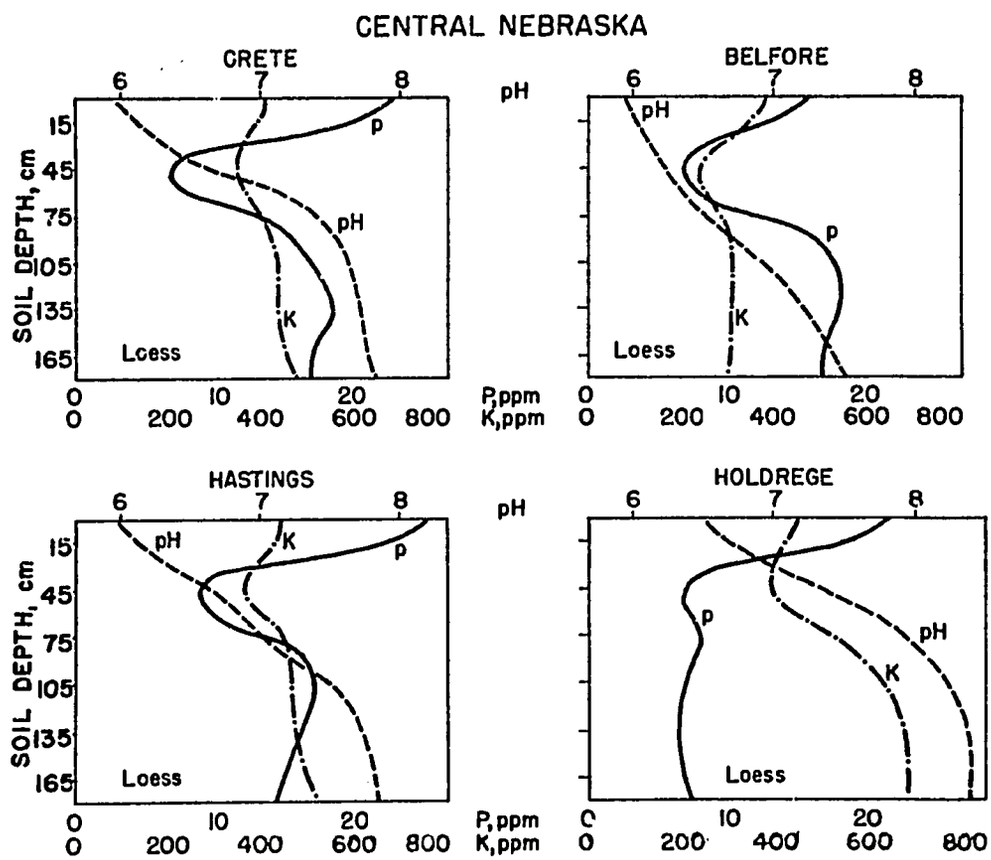

Fig. 4. Soil P (Bray & Kurtz #1), exchangeable K and pH levels of the 180 cm profile of major soils in central Nebraska; mean values determined from several locations of each soil series.

In the case of the fallow-wheat cropping experiments in a region with 40-58 cm annual rainfall, yield response was negative at 45 and 67 kg N/ha application rates when residual NO_3-N exceeded 135 kg/ha. No response occurred above 22 kg N/ha when the residual was between 90-135 kg/ha, whereas the response curve leveled out with the intermediate applied rate when the residual ranged between 45-90 kg/ha. With less than 45 kg N/ha residual, the response curve was still rising steeply at the 67-kg application level. Clearly, it should be a matter of real concern in wheat nurseries to know whether additional N as fertilizer would be required for top performance of the genetic material under evaluation, and alternatively, if added increments were likely to have depressional effects.

Not only do the locations with low residual mineral soil N show maximum response to applied N and conversely, but lower protein levels result across the range of treatments on deficient soil. Nor was the protein level made equivalent with even the highest N treatment of the soil employed in these experiments, suggesting that some modest level of soil residual N must be present for maximum combined yield and protein expression (Table 2). Probable explanation is that declining root activity from the surface downward through the season as moisture is progressively depleted prevents full utilization of even heavy fertilizer treatment from the upper soil horizon in the year of application.

Table 2. Protein content of wheat in response to applied N for experiments of Figure 3.

Soil residual NO_3-N	N applied, kg/ha			
	0	22	45	67
kg/ha	percent			
	Continuous Cropping			
<45	10.6	11.0	11.3	11.8
45-90	11.3	11.7	12.5	12.9
>90	12.0	12.4	12.9	13.2
	Fallow Wheat			
<45	9.0	9.4	10.0	10.8
45-90	9.3	10.1	10.8	11.7
90-135	10.6	11.2	11.8	12.5
>135	11.2	11.8	12.3	12.8

Reliability of Soil Tests

Soil testing methods have been refined to the extent that reliable prediction can be made of nutrient needs for crops grown on most soils. Reliability depends first on the collection of representative samples, thereafter on proper handling, authentic testing methods, and valid interpretation based on a sound correlation and calibration background.

Among the primary elements of plant nutrition, measurement of the plant availability of only soil N has remained largely enigmatic. The data of Table 3

acquired from 119 field experiments during the 1950's indicate that the nitrate production test quite effectively delineated between response and non-response situations. It is an adequate test for situations where the wheat crop is largely dependent on N mineralized from the surface soil's organic matter supply. By 1960, however, it became evident that another nutrient N source would have to be considered in Nebraska, viz., that mineral N remaining as residual in the soil profile from previous years' fertilizer N application.

Earlier correlation work on soil testing at Nebraska had indicated the efficacy of an organic matter determination to reflect N status on a single soil type in a given climatic region. The measurement lost significance, however, when carried out on soils widely divergent in morphological properties, such as pH, texture, base saturation, clay type, etc. Readily decomposable portions of the total organic matter fraction have similarly failed of credibility as a N measure when investigated across a broad gamut of soils. Mineral N accumulations in the lower portion of the rooting profile no doubt contributed to the limited usefulness of organic matter values for assessing soil N status.

Most of the soil testing calibration work reported in the literature has been accomplished with surface soil samples only. It has become increasingly evident that additional nutrient information from the rooting profile of soil is needed, especially for the more mobile nutrients like N and S. Calibrations must be developed for each crop species in any soil region and will likely require modifications with the introduction of new genotypes of greater yield potentials.

Table 3. Calibration of soil nitrate production test with supplemental N needs for winter wheat in Nebraska field experiments, 1952-1959 (6).

Nitrate production (NR) range and interpretation 1/	Locations with Increase to N	No effect of N	Decrease to N	Fertilizer recommendation
ppm NO_3-N	percent			kg N/ha
Response assured				
C 0-15	97	3	0	4 -67
F 0-10	100		0	33-45
Response likely				
C 15-20	75	25	0	33-45
F 10-14	50	22	28	22-33
Response possible				
C 20-25	50	50	0	22-33
F 14-18	42	19	39	22
Response unlikely				
C >25	0	100	0	None
F >18	0	27	73	None

Correlations 2/

Continuous Cropping	Y=52.1 - 1.85 X	r = -.630**	(n=59)
Fallow Wheat	Y=17.9 - 1.04 X	r = -.463**	(n=60)

1/C = continuous cropping; F = after fallow

2/Y = yield response in % of max. yield; X = NR in 10^d

Table 4 presents recent correlation information for the winter wheat crop in respect of the elements N and P. These are the elements most extensively required for wheat production in Nebraska. It is apparent that neither of the N testing procedures investigated on surface samples alone is useful for predictive purposes, with less than 25 percent of the variation explained by the regression equation. The 180-cm profile value for residual NO_3-N, however, does rather effectively indicate probability of response to applied N. By further integrating the surface soil's nitrification capacity in multiple correlation, 41 percent of the variation in yield is explained.

Table 4. Regression analyses relating soil testing values for N and P with yield response of winter wheat to applied fertilizer (115 field experiments in Nebraska, 1960-68).

Variable (x) related to % yield response	Regression equation[1]	Correlation coefficient[2] r
	NITROGEN	
Surface soil NO_3-N	$Y = 66.5 - 1.14799X$	0.481^{**}
Surface soil NR	$Y = 49.72 - 1.08136X$	$.241^{*}$
Profile NO_3-N	$Y = 103.87 - .01279X + .0041432X^2 - .0000034X^3$	$.624^{**}$
Profile NO_3-N + NR	$Y = 119.61 - 1.33750X + .0040270X^2 - .0000032X^3$	$.643^{**}$

Calibration for profile NO_3-N

NO_3-N, kg/ha	Calibration range
0 - 45	Response assured
45 - 90	Response likely
90 -135	Response possible
>135	Response unlikely

PHOSPHORUS

Surface soil P	$Y = 36.91 - 1.69102X + .0187306X^2$

Calibration for surface soil P

Bray P, ppm	Calibration range
0 - 15	Response assured
15 - 23	Response likely
23 - 30	Response possible
>30	Response unlikely

[1]X = soil test value in ppm; Y = yield response from applied nutrient in percent; NR = soil nitrate production in 10 days

[2]* = significant at 5% level; ** = significant at 1% level

The P correlation data for field experiments with wheat in Nebraska from 1960 to 1968 fortify interpretations made from field studies prior to 1963. There is no cause for altering the conclusions made at that time, nor is there need for adjusting calibrations made then. In this case, no benefit is derived from integrating deeper profile information on P. The relationships expressed for N and P testing become the more meaningful as recognition is given to varied climatic conditions over the 9 years of study, different varieties employed, differential farming practices, and the wide range of morphological soil units involved across the state of Nebraska.

Meaningful correlation data from soil testing necessitate a reasonable level of moisture availability and certainly more efficient utilization of water can be expected as nutrient deficiency is corrected (10). A crop suffering severe drouth stress will produce a maximum yield with substantially lower levels of most available nutrients than are required for top yields when moisture is adequate. On the other hand, hard red winter wheat varieties presently grown on the Great Plains of the U.S. do not afford the best yield response to fertilizers in years of above-normal rainfall, especially if excess moisture comes during the head-forming and grain-filling stages. For these reasons, poor correlations are found as yields and moisture availability are related over several years (7), and there is little reason to expect improved correlation of soil testing results with yield response by integrating the additional moisture factor unless it is never excessive.

While on the subject of soil testing, reference should perhaps be made to the use of plant analysis for evaluating crop nutrient needs. Plant analysis has proved to be a useful research tool, helping to explain why a crop is doing well or poorly, but the information acquired is post mortem insofar as the current crop is concerned. Where used, the most meaningful information is obtained from the upper leaves of wheat collected just before heading.

Nutrient Variability in Field Soils

Figure 4 depicts differences in nutrient levels that are found in Nebraska soils classified on a soil series basis that are the consequence of pedogenic processes in soil formation. Although all four soil series represented are fairly similar in surface soil pH and all become alkaline from calcareousness with depth, there is appreciable difference in the depth at which the free lime is expressed. All of these soils are high in exchangeable potassium throughout the profile with Holdrege being especially high in this component. Surface adsorbed phosphorus levels are more variable, Holdrege containing much less in its lower profile than the others. None of these apparent differences could be adjusted to uniformity by feasible means and they do have nutritional implications. A winter wheat nursery made up of half Hastings and half Holdrege soil could be expected to express varied growth characteristics of the wheat crop on opposite sides of the dividing line which were nutritionally related.

The wheat nursery represented in Figure 5 on the Mead Field Laboratory of the University of Nebraska is of very uniform surface topography, and morphological characteristics of the soil profile visible to the naked eye other than thickness of A horizon do not vary throughout the area. Nonetheless, significant variations do exist in surface soil pH as well as mean pH of the 180-cm profile. It is quite likely that the half unit of pH from the areas of lowest mean profile value to the highest levels would have nutritional significance.

Variations in available soil P levels are even more striking for this 'uniform' nursery (Figure 6). A fairly consistent gradient exists from southwest to northeast for the surface soil, from a medium calibration range to a very high level. Profile mean values depicted in the lower half of the figure, however, vary even more and not exactly in conformity with the surface soil values. The differences expressed, especially throughout the profile, are more than enough to account for appreciable variability in crop growth under moisture stress conditions. The surface soil differences could be equalized quite readily by fertilizer treatment, but the profile discrepancies could not be corrected by practical means in any reasonable time interval. There is good reason to believe that erratic yield data acquired in years of excessive or deficient moisture are related to the high or low availability of P throughout the profile.

Soil mineral N (NH_4^+ plus NO_3^-), expressed in Figure 7, also evidences more than a two-times range within the nursery plot area despite uniform fertilizer N treatment during the last six years. As with P, the surface soil and the 180-cm profile do not tell a common story. The delineations made on the chart for profile N are all gradations of 'high' calibration, and it seems quite probable that excessive N could be a yield-limiting factor for some varieties over a considerable portion of the nursery, judging by the criteria of Figure 4. An overabundance of available N, together with the nutrient P situation depicted above, may largely explain the plant breeders' general dissatisfaction with the site.

No simple way exists for explaining the variability in the soil pH and nutrient status expressed in Figures 5-8. Natural effects from pedogenesis may be partially involved although no differences are apparent in visual properties of the soil profile involved. The site being an ancient terrace with a loess cap on a hummocky sand surface, it is possible that the capillary discontinuity of the underlying sand at varied depth influenced root movement and magnitude, ultimately nutrient accumulation in the profile during genesis.

Long-forgotten field boundaries with differential management of the soil on opposite sides could explain some of the differences observed at the present time. Especially would an area exposed to a high livestock density for a period of time in the past be likely to show appreciable P accumulation in the upper profile and N throughout. Even a human living site with associated small animal life will evidence high P concentration of the soil for as long as centuries after the habitat has been leveled and forgotten (3). Such possibilities need investigation by thorough profile sampling and soil analyses prior to the establishment of long-term wheat nurseries.

Summary

Soil fertility exerts a major role on the yield and quality of winter wheat wherever produced. Although deficiencies of N, P and K are most likely to limit production in wheat-producing regions of the world, shortages of other elements are being increasingly recognized with introduction of varieties of higher yield potential and with application of improved overall soil-crop management systems. With the exception of a few elements like Fe and Mn, authenticated methods have been developed for soil nutrient evaluation by soil testing which should prove invaluable to the researcher responsible for varietal evaluation in wheat nurseries. Not only is knowledge of nutrient level needed for preventing deficiency, but this information is essential for preventing excesses that may be responsible for yield reduction due to toxicity or unfavorable interaction with

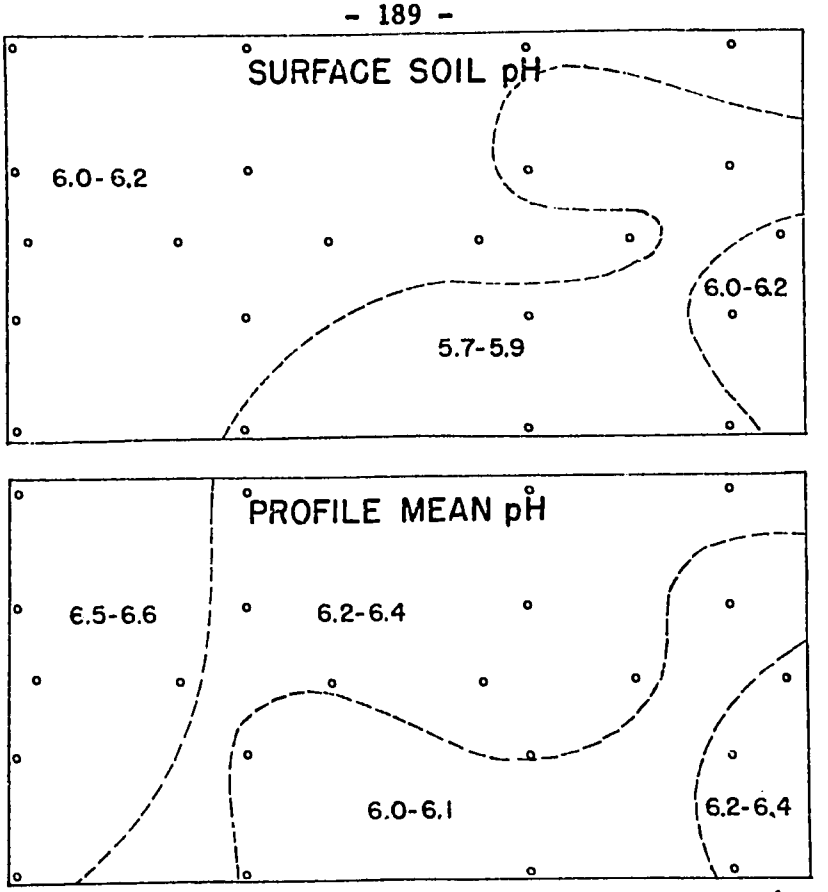

Fig. 5. Soil pH in the winter wheat nursery at the Mead Field Laboratory, Nebraska. Upper chart is for surface soil to 15 cm; lower chart expresses mean pH for the 180 cm profile.

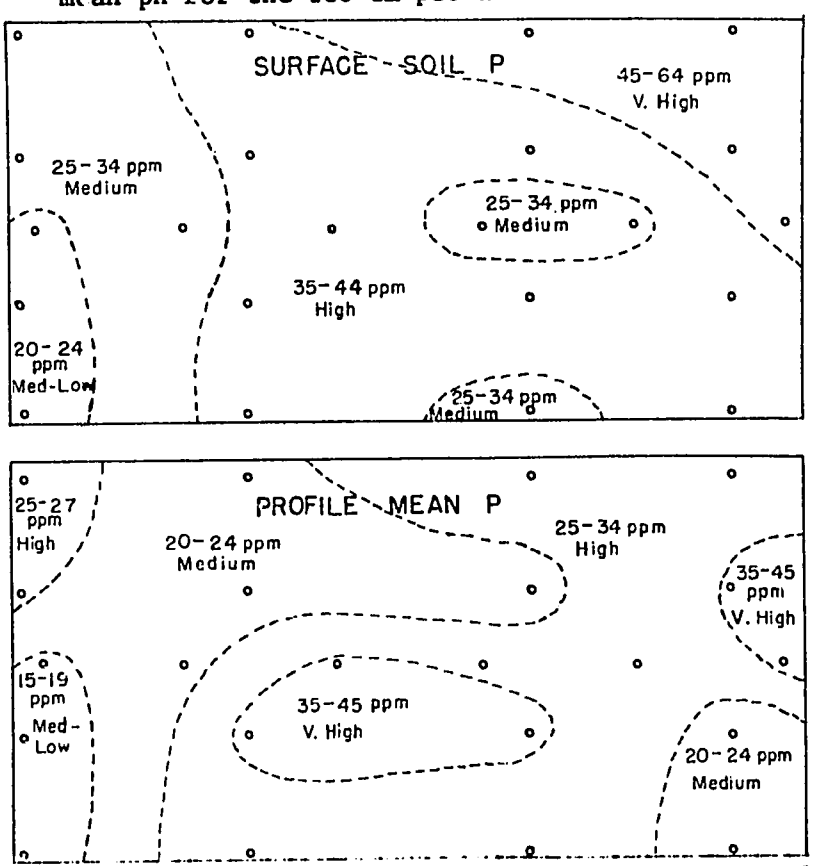

Fig. 6. Available P (Bray & Kurtz #1 levels in soil of the winter wheat nursery at the Mead Field Laboratory, Nebraska. Upper chart is for surface soil to 15 cm; lower chart expresses mean P value for the 180 cm profile.

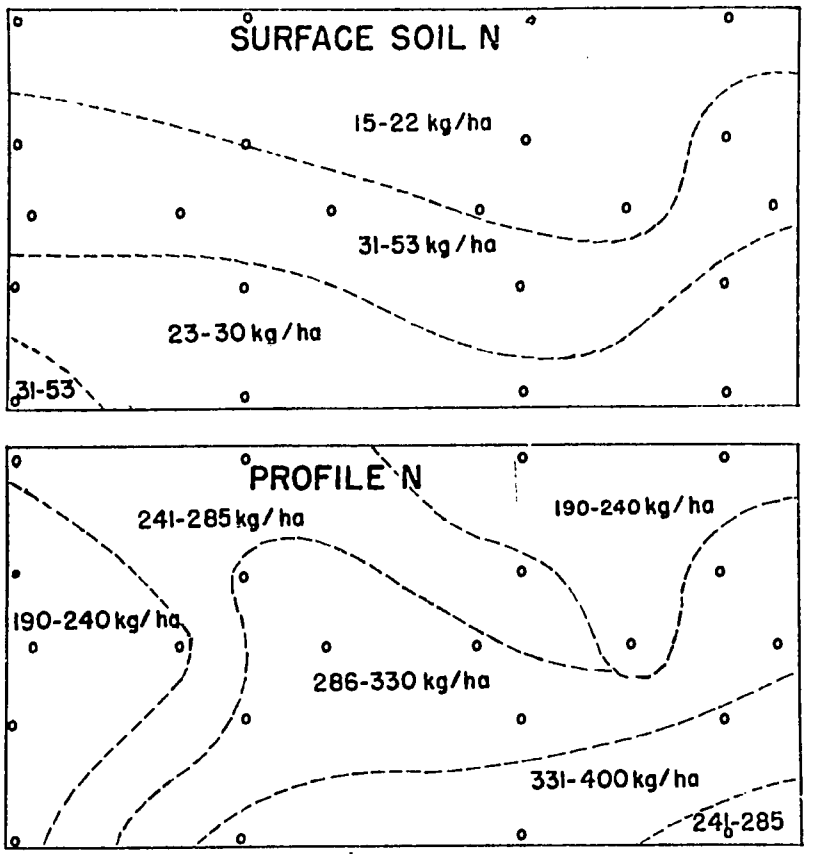

Fig. 7. Mineral soil N (NH_4^+ and NO_3^-) levels in soil of the winter wheat nursery at the Mead Field Laboratory, Nebraska. Upper chart is for surface soil to 15 cm; lower chart expresses total mineral N for the 180 cm profile.

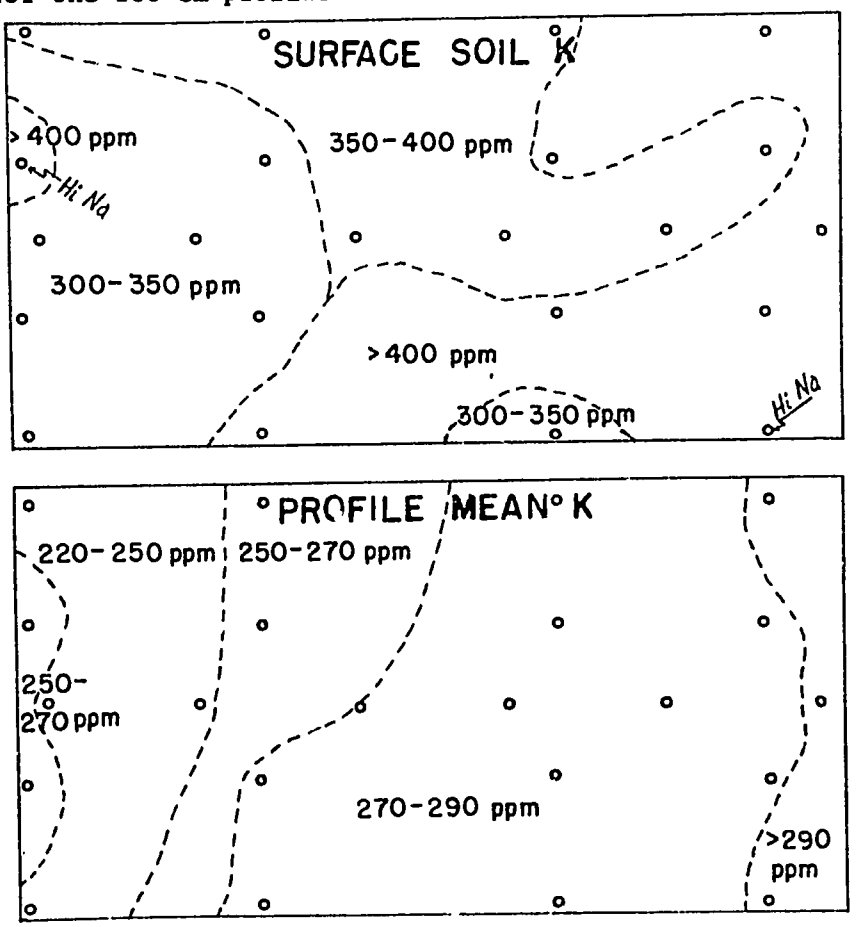

Fig. 8. Exchangeable K levels in soil of the winter wheat nursery at the Mead Field Laboratory, Nebraska. Upper chart is for surface soil to 15 cm; lower chart expresses mean exchangeable K for the 180 cm profile.

another essential element of plant nutrition. Nurseries should be established under optimum fertility conditions as it is important for plant breeders to be certain that varietal differences in yield at a given location are not reflections of genotype selectivity in nutrient uptake.

Protein content as a wheat quality factor varies radically with environmental changes, including those associated with soil nutrient levels. With N limiting at a constant level, growth factors like improved moisture availability that result in increased yield cause an inverse effect on protein content due to dilution of the quantity of N available in the higher yield. When residual mineral N in soil is low and with favorable growing conditions otherwise, the predominant effect of the first increments of applied N will be to increase yield, whereas with high residual soil N the dominant effect will be to increase protein content. The low residual N site will not produce the same protein content with any reasonable rate of applied N as the site with high residual N. Explanation proposed is that declining root activity with moisture depletion from the surface downward through the growing season prevents effective utilization of even heavy N treatment to the surface horizon. Some modest quantity of available N must exist in the lower soil horizons where root activity is likely to be greatest during the grain-forming and protein-setting stage.

Thorough sampling and analysis of the soil profile within a proposed wheat nursery area should be accomplished before plot establishment. Such procedure will preclude the possiblity of later experiencing serious variability in measurements of yield and quality due to soil fertility gradients. A close collaboration among plant breeders, nutritionists, and soil fertility personnel will be required for achieving major advances in wheat production potentials henceforth in view of the many interacting factors recognized at this conference.

References Cited

1. Borlaug, Norman E. 1971. Mankind and civilization at another crossroad. McDougall Memorial Lecture, FAO, General Conference, 16th Session, Rome.

2. Cummings, Ralph W. and Ralph N. Gleason. 1971. The role of fertilizer in agricultural development. In Fertilizer Technology and Use, R. A. Olson et al. (eds.), Soil Sci. Soc. Amer., Madison, Wis.: 1-25.

3. Dauncey, K. D. M. 1952. Phosphate content of soils on archaeological sites. Advance Sci. 9: 33-36.

4. Foy, C. D., G. R. Burns, J. C. Brown, and A. L. Fleming. 1965. Differential aluminum tolerance of two wheat varieties associated with plant induced changes around their roots. Soil Sci. Soc. Amer. Proc. 29: 65-67.

5. Olson, R. A. 1972. Fertilization of non-irrigated wheat in regions of moderate and low rainfall. This conference.

6. Olson, R. A., M. W. Meyer, W. E. Lamke, A. D. Woltemath and R. E. Weiss. 1960. Nitrate production rate as a soil test for estimating nitrogen requirements of cereal crops. 7th Int. Cong. of Soil Sci. Vol. II: 463-470.

7. Olson, R. A., C. A. Thompson, P. H. Grabouski, D. D. Stukenholtz, K. D. Frank, and A. F. Dreier. 1964. Water requirement of grain crops as modified by fertilizer use. Agron. J. 56: 427-432.

8. Smika, D. E. and B. W. Greb. 1972. Protein content of winter wheat grain as related to soil and climatic factors in the semiarid central Great Plains. Agron. Abs.

9. Terman, G. L., R. E. Ramig, A. F. Dreier, and R. A. Olson. 1969. Yield-protein relationships in wheat grain as affected by nitrogen and water. Agron. J. 61: 755-759.

10. Viets, Frank G., Jr. 1962. Fertilizers and the efficient use of water. Adv. in Agron. 14: 223-264.

11. Wright, B. C. 1972. Fertilization of irrigated winter wheat. This conference.

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