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FERTILIZATION OF NON-IRRIGATED WHEAT IN REGIONS OF MODERATE AND LOW RAINFALL

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by

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Moisture has long been recognized as the number one limiting factor in the production of winter wheat in the dry regions. Certainly this growth factor cannot be overlooked wherever rain-fed cropping is practiced under semiarid to arid climatic conditions, and all possible must be done toward moisture conservation. Recognition of this requirement has been responsible for the development of the suite of practices embodied in 'dry farming' in these regions. It has become increasingly apparent in recent years, however, that moisture conservation cannot be overemphasized to the exclusion of all else, most specifically the fertility requirements of the wheat crop.

With moderate rainfall as occurs in subhumid climatic regions, fertility needs are generally well recognized. In this situation, convincing farmers of the need for fertilization is usually less difficult than relaying educational details concerned with precisely which nutrients are needed and effective fertilizer management practices for the nutrients involved.

Effective Fertilizer Management Practices

Kind of Nutrient. It is generally recognized that N and P are the nutrients most likely to be deficient for optimum yields throughout the wheat-producing regions of the world. Supplemental K need is less common, in considerable part because wheat is conventionally grown in drier regions where inherent soil K levels are notably higher than in the humid regions.

The data of Table 1 summarizing 1284 simple trials and demonstrations of the FAO Fertilizer Programme in 1966/67 give evidence of the general NP requirement of the wheat crop and the good probability of a highly profitable response to the application of these nutrients in all but the very driest regions. A summary of 133 simple fertilizer trials on winter wheat in the Near East-North Africa region, for example, showed the following main effects in kg/ha: N +235; P +225; and K +65 (3).

Calcium and Mg shortages limit yields even less commonly than K, and for the same reason. Deficiency of S has become increasingly apparent, in part due to higher yield potential of improved varieties and because of decreasing amounts of S 'impurity' in carriers of primary nutrients and in applied pesticides. Especially are sandy soils of low organic matter content and the more thoroughly leached soils (of whatever texture) in humid regions likely to be S deficient. Yield limitation from shortage of one or more of the trace elements Zn, Fe, Mn, Cu, Mo and B is also being noted more and more frequently. The bases among this group are especially likely to be deficient with heavy applications of the primary nutrients for high yields on calcareous soils.

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It perhaps goes without saying that wheat grown in nurseries for evaluation purposes should never suffer for lack of nutrient. Soil and plant tissue testing with adequate research base of correlation and calibration can give invaluable assistance in determining the kind of nutrient(s) required. This is the topic of a later presentation in this conference. Suffice it to say at this point that something better than an educated guess based on experience on adjacent soil is needed.

Table 1. Response of non-irrigated winter wheat to fertilizers in demonstrations and trials of the FFHC Fertilizer Programme of FAO, 1966-67 (2).

Country and Region	No. of sites	Average Yield of Control	Yield increase to Fertilizer*				Value/cost ratio of best treatment
			N	P	NP	NPK	
		kg/ha	%	%	%	%	
Colombia							
Narino	14	1135	36	--	62	50	3.7
Narino	6	1974	30	4	33	38	5.2
Guatemala							
West Plateau	10	1427	--	--	93	99	1.8
Lebanon							
South Lebanon	9	1125	49	16	79	120	3.6
Bekaa	15	1631	17	18	17	15	1.7
Morocco (Southern)							
Hard wheat	63	742	--	22	38	--	1.3
Soft wheat	7	272	--	105	234	--	1.7
Syria							
Anti-Lebanon foothills	6	967	--	23	40	59	1.3
Southern Provinces	10	1052	--	24	38	40	1.3
Jezireh	14	1207	--	45	86	57	2.8
Western Plains	36	1026	--	42	57	73	2.4
Turkey							
Black Sea Coast	53	1065	--	33	66	--	3.3
Thrace and Marmara	39	982	--	23	73	--	2.2
Aegean Coast	24	1108	--	37	107	--	5.0
Mediterranean Coast	284	981	--	33	78	--	3.0
Southwest Coast	54	995	--	--	90	117	3.1
Northern Transition	171	254	--	35	68	--	2.6
Southern Transition	37	957	--	53	77	--	3.2
Central Anatolia	432	758	--	63	--	--	2.7

*Rate of N was generally between 20-60 kg/ha, P_2O_5 between 40-60 kg/ha, and K_2O between 30-40 kg/ha.

Rate of Nutrient. Appropriate rate for a deficient nutrient is governed by the amount residually present within the crop rooting depth of soil, the soil's capacity for releasing the nutrient, the crop demand, and to some extent the environmental conditions surrounding the crop's growth. Where little or no regard is paid to the first three of these criteria, deficiency or excess of the nutrient involved is likely to result, either of which can impose yield limitation with at least some nutrients.

The data of Figure 1 demonstrate the varied responses that are obtained in a given region, from positive in a part of the locations to progressively more negative in others with increasing N rate.

No standard rate can properly be assigned for a given region based on averages of a few trials, since different soils do vary tremendously in nutrient supply from pedogenic processes (1) and from previous management. Note the substantial differences in available P and K contents of the profiles of western Nebraska soil series expressed in Figure 2. Although they occur intimately associated, P deficiency is common with the Ulysses soil and is unknown with the Kuma. It is especially necessary that rate of any deficient nutrient be adjusted to moisture supply likely to be available to the crop as discussed in a subsequent section.

Time of Application. The proper time of application of a fertilizer nutrient varies in accordance with mobility of the nutrient in soil and time of major crop demand. On the one hand, wheat absorbs most of the N required for high yields between the period when growth commences in the spring and the heading stage, and commonly gives maximum response in grain and protein yield per unit of N when applied in the spring rather than in the fall at planting (5). This fact also permits evaluation of moisture stored and available for crop use well into the growing season, thereby alleviating the overstimulation hazard from fall N application depicted in Figure 1. It also precludes disease problems incidental to excessive fall vegetative growth with fall applied N in some years.

Phosphorus and other immobile nutrients, on the other hand, must be applied at or before planting in order to be present in the crop rooting zone as growth commences. There is minimal leaching of such elements into the soil if broadcast after planting, and since almost no root activity occurs at the soil/air interface little other than a small amount of foliar absorption is likely to occur.

Chemical Carrier of Nutrient. Time and space do not allow complete treatment of the question of nutrient carrier since there is such a very large number of products on the market. Among the more common N products such as anhydrous ammonia, ammonium nitrate, ammonium sulfate, calcium ammonium nitrate, urea, and nitrogen solutions of one or more of these carriers, little or no difference in agronomic effectiveness is likely to be measured so long as each carrier is used according to its own limitations. Recently developed sources of a controlled release nature, however, may prove quite superior or inferior depending on environmental conditions.

Phosphatic materials on the fertilizer market vary markedly in their relative availability to the wheat crop. Their effectiveness is also very much influenced by soil character. Some materials that are highly effective on acid soils are much less so on calcareous soils (e.g. DAP, ACSP, CMP in Table 2). Associated NH_4+ and high water solubility combine in assuring immediate plant availability and maximum plant uptake with most effective placement. Particle size of the P carrier is important in the fact that coarse granulation is advantageous for high solubility materials for minimizing fixation, while very fine division and thorough mixing with soil is essential for carriers low in water solubility. Under reducing conditions of very strong acidity some materials like basic slag in a mixed treatment may prove fully equal to any other listed. Superiority of the slag has been measured occasionally in which case base and trace element 'impurities' must be presumed to have contributed.

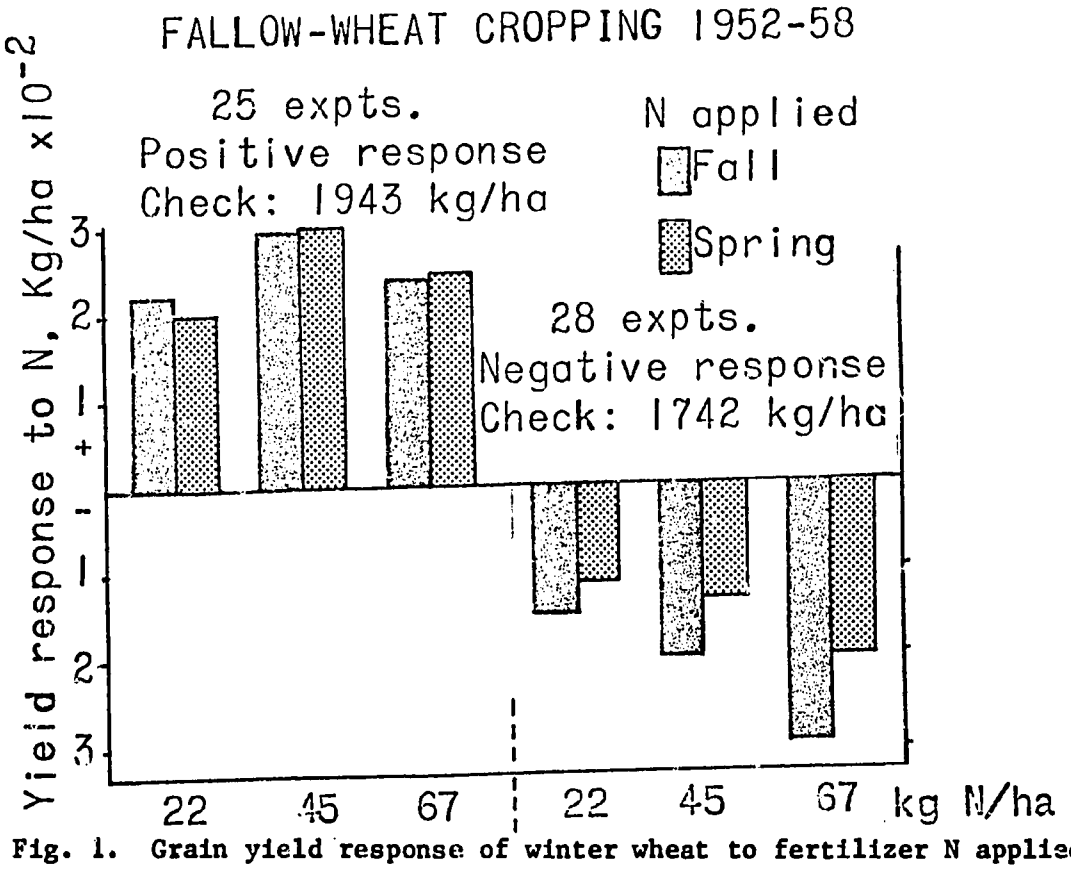

Fig. 1. Grain yield response of winter wheat to fertilizer N applied in the fall and spring under fallow-wheat cropping at 77 locations in western Nebraska, 1952-58. All N treatments broadcast as ammonium nitrate; 24 locations (not plotted) evidenced no response to N (4).

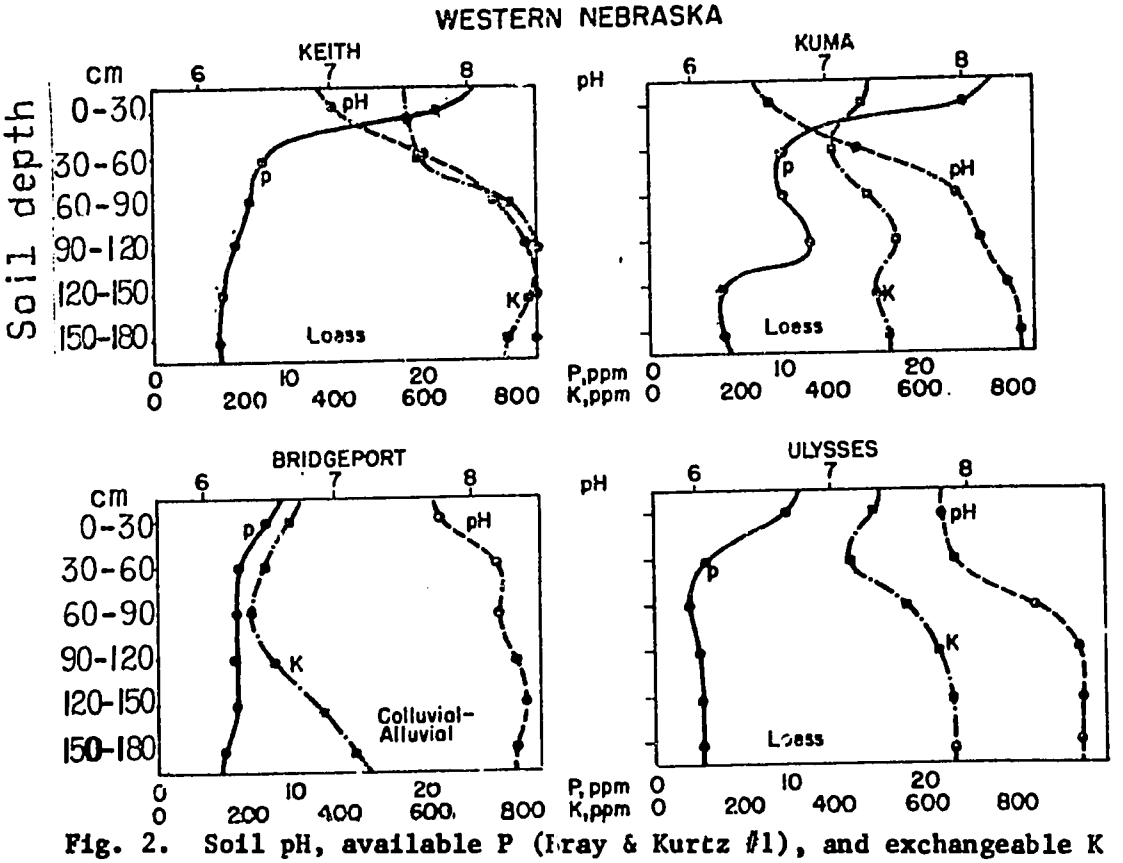

Fig. 2. Soil pH, available P (Bray & Kurtz #1), and exchangeable K for the 180 cm profile of representative soils of western Nebraska.

In the case of carriers of most nutrients a high degree of water solubility will usually portend ready plant availability and conversely. There are exceptions, of course, as with elemental S used as S fertilizer, basic slag for P, ZnO for Zn, etc. With all of these, however, the material must be very finely divided and mixed well into the soil rather than banded for maximum crop utilization. Such fine materials are difficult to apply.

Table 2. Relative availability of phosphatic fertilizer materials for annual crops grown under Nebraska conditions.

Annual crops grown on moderately acid soils
APP, MAP, DAP ≥ PA, CSP, ACSP, OSP, wsNP, CMP > DCPdi, lwsNP > RhP, BS, DCPan, FTP > RP > 0

Annual crops grown on calcareous soils
APP, MAP, PA ≥ DAP, CSP ≥ ACSP, OSP > NP, CMP, RhP, DCP > FTP, BS, RP = 0

Names abbreviated as follows: Ammoniated PolyPhosphate, MonoAmmonium Phosphate, DiAmmonium Phosphate, Phosphoric Acid, Conc. SuperPhosphate, Ammoniated Conc. SuperPhosphate, Ordinary SuperPhosphate, Nitric Phosphate (water soluble, low water solubility), Calcium MetaPhosphate, DiCalcium Phosphate (dihydrate, anhydrous), Rhenanian Phosphate, Basic Slag, Fused Tricalcium Phosphate, Rock Phosphate

Fertilizer Placement. Proper fertilizer placement is necessarily concerned with achieving high efficiency in crop utilization of the applied nutrient and with prevention of deleterious salt effects to germination. A carrier like anhydrous ammonia must be injected sufficiently deep into the soil with immediate closure of the injection slot to prevent serious gaseous loss to the atmosphere. Urea applied to calcareous soil requires some incorporation to prevent ammonia volatilization loss from the unstable ammonium carbonate produced by the enzymic hydrolysis of this carrier. All of the common N materials are possessed of a high salt index such that care must be exercised to assure limited contact between fertilizer and seed. As little as 10 kg N/ha placed in the row can have damaging effects on wheat germination if soil moisture is limited and rain is long delayed subsequent to planting. It is also important that very small amounts of most trace element carriers be allowed to enter the seed row because of toxic effects on seedlings.

Phosphate banded in or very near to the seed row of wheat has commonly been found to give greatest yield effect per unit of applied P in acid soils. The enhanced response can be attributed to the positional availability and rapid early uptake of this nutrient (as is required for best growth of the crop) and to retarded fixation loss in some soils. Such banding has not proved to be as necessary for maximum utilization efficiency on calcareous soils.

Hazards of Excessive Fertilizer

Crop Lodging. One of the major problems resulting from overfertilization of the winter wheat crop has been that of lodging. Especially has nutrient N been suspect in this regard with traditional varieties of wheat grown in the drier climatic regions. Excessive N favors rank leaf and stalk growth which with increased shading causes succulent and weak stalks that do not stand well under beating rain and wind action. Kernels of wheat on lodged plants do not fill well and portions are commonly lost in the harvesting operation. The development of stiffer strawed varieties in recent years, especially dwarf types, has alleviated the problem to some extent. Lodging from excessive nutrient does remain a problem, though, for most regions where strong winds may accompany rains received after heading of the crop.

Imbalances Created. Excessive amounts of any one of the soil-derived elements of plant nutrition can have deleterious effects on crop growth from the standpoint of an imbalance in the nutrients required if not outright toxicity. It is to be expected that force-feeding the plant excessive amounts of a given nutrient must necessarily dilute the amount of some other nutrient taken up, and if the diluted one chanced to be at a marginal level initially, an induced deficiency would result. The literature reports numerous examples of nutrient deficiency created by excessive application of another element, e.g., Zn and Fe by P, Fe by Zn, Fe by Cu, Mg by K, etc. It behooves the plant breeders in establishment of nurseries for evaluation of genetic materials to know something about nutrient levels in the soil for preventing problems of this nature from blanket fertilizer treatments. The use of so-called 'balanced fertilizers' is not necessarily the answer since balance must be accomplished between soil nutrient delivery capacity and nutrients added.

Overstimulation. Farmers as well as agricultural technicians have commonly experienced the overstimulation of crops accompanying high fertility in the drier regions. Their apprehension stems from the nutrient supply causing excessive vegetative stimulation at the expense of grain yield as moisture runs out. The problem in this respect has been most acute with N which has greatest stimulative action on vegetative development. The hazard has frequently been accentuated with fallowing which in itself is responsible for substantial mineral N accumulation in soil.

More often than not, where overstimulation probability is the accepted reason for excluding N treatment, the experience has come from application at rates proved economic for more humid regions. Reducing rate to a more compatible level with the moisture supply available will frequently result in positive fertilizer benefit. It is the author's belief, for example, that a N treatment of 10-20 kg/ha would prove economic in most years on the majority of soils of even the central Anatolia plateau of Turkey.

A further aspect of N management is crucial here in respect of timing. Nitrogen applied in the fall at or before planting is likely to stimulate excessive fall and early spring vegetative growth and be responsible for considerable moisture depletion. Such depletion can be at the expense of yield in the following summer if seasonal rainfall is deficient (note Figure 1). Delayed spring application, on the other hand, will not have as great an effect on vegetative development and may well result in sufficient moisture remaining for fulfilling grain yield requirements. The data of Figure 3 support this contention in showing less water consumed and a greater water use efficiency by the crop with spring than with fall N treatment.

Water Use Efficiency

The fact that crops make more efficient use of water in producing grain as soil fertility increases from a deficiency state is well established (8). This benefit has been measured commonly wherever fertilizer treatment increased yield of crop. The registered effects are the result of more efficient production and storage of carbohydrates in the grain-forming process when nutrients accessible to the crop are adequate. Note in Table 3 that yield increased with increasing

amounts of available water at planting, and with rate of N application. Water use efficiency increased correspondingly from applied N but only as water was nominally available, reaching its maximum with the higher N rates and the 15 cm preplant water application (7). This study with continuous cropping in a semiarid region indicated the need for 22 kg fertilizer N/ha for each 7 cm available preplanting soil moisture on the soil involved.

Table 3. Effect of preplanting soil moisture and rate of N fertilization on yield and water use efficiency of winter wheat at North Platte, Nebraska, 1954-56.

N applied, kg/ha	Available soil water at seeding, cm*			
	0	7	15	21
	GRAIN YIELD, kg/ha			
0	473	1013	1283	1350
22.5	675	1418	1890	1958
45	608	1688	2160	2363
90	540	1688	2498	2633
	WATER USE EFFICIENCY, kg/ha-cm			
0	16	26	32	30
22.5	22	36	45	41
45	19	44	48	47
90	16	41	54	51

*Yield response values are average for spring and fall applications of N.

Other studies throughout Nebraska on representative soil and cropping situations have demonstrated a mean production of 70 kg wheat/ha-cm of water by the fertilized crop compared with 62 kg/ha-cm or an increase of 12% in water use efficiency at the same time that yield increased an average 21% (Fig. 4). In some cases fertilizer treatment had a detrimental effect on water utilization, associated with lack of positive yield response, while in others with very great fertilizer response, water effectiveness was enhanced more than 100% by treatment (6). Nebraska results do not corroborate some reports in the literature suggesting that the greater production per unit of water consumed by fertilized crops is accomplished without noticeable increase in total water consumption. As noted in Fig. 4 we found an average additional 2.5 cm of water consumed by the fertilized crop. Explanation for the greater total use is given as a more active root system with greater moisture extraction capability in the area of root proliferation as well as deeper root extension through fertilization for extraction of any existing deep subsoil moisture. Thus, the residual soil moisture following a well-fertilized crop is likely to be slightly less than that remaining without fertilization.

An appropriate summation of this section would be that fertilizers will not substitute for water, but where needed they will assist the growing crop in making better use of that which is available. For soils of moderate fertility level, the increased efficiency from fertilization will approximately equal the proportionate increase in yield, but not quite due to the small amount of extra water consumed. Balancing the level of fertility for the wheat crop with the moisture supply likely to be available for its production thus becomes of the essence.

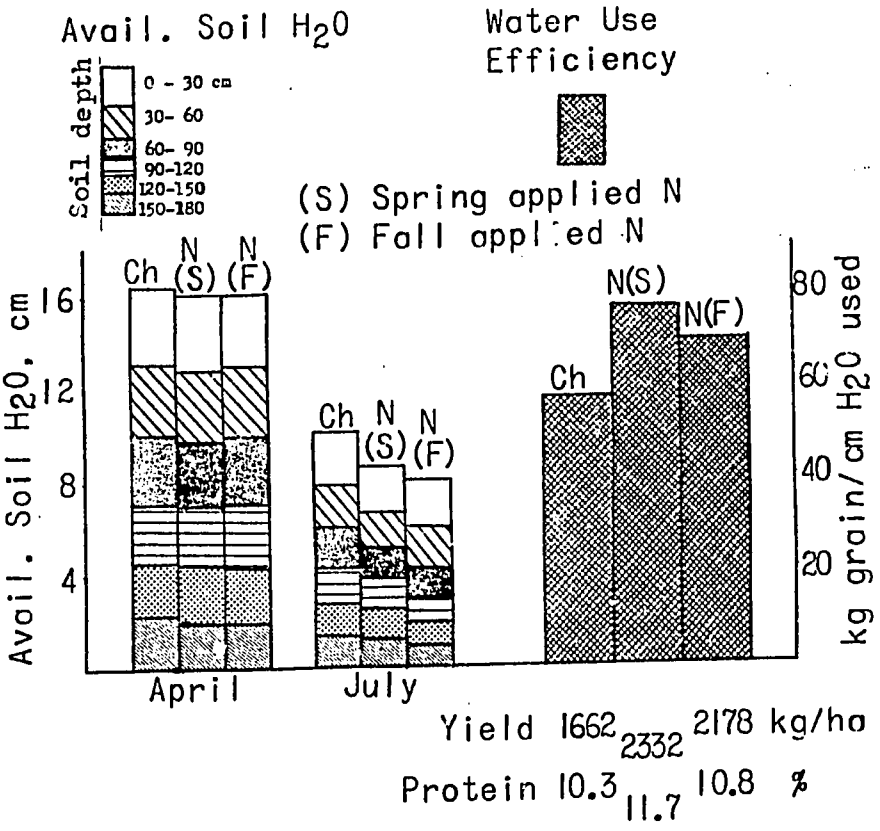

Fig. 3. Grain yield, protein percentage and water use efficiency in 16 field experiments with winter wheat in western Nebraska as affected by time of applying 45 kg N/ha, 1962-65.

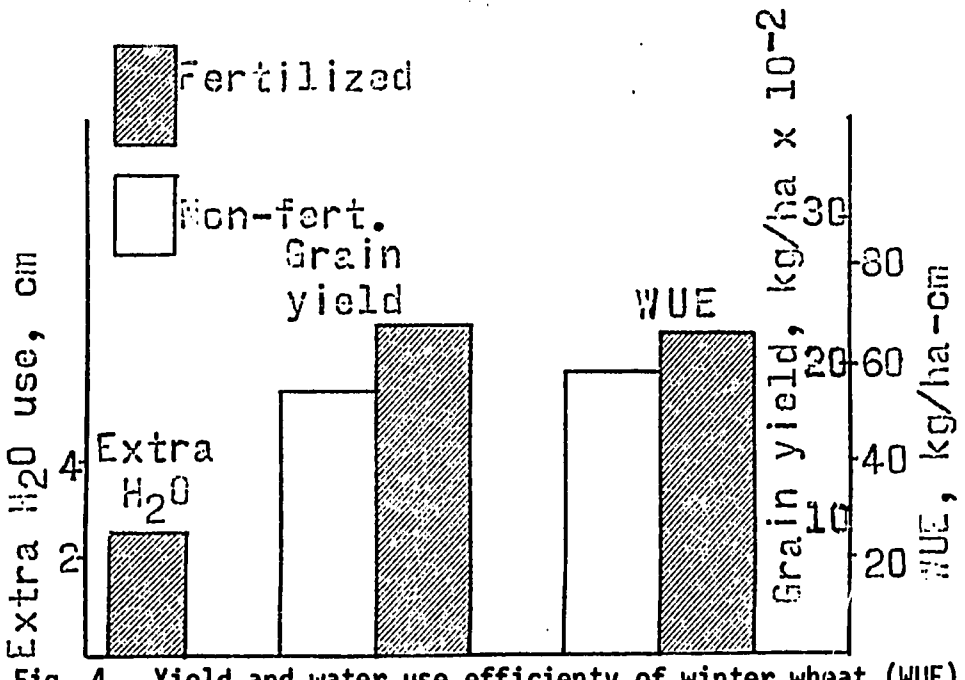

Fig. 4. Yield and water use efficienty of winter wheat (WUE) in Nebraska as influenced by optimal fertilizer treatment in 41 field experiments of 1962-64.

Fertilizer Use and Crop Quality

Wheat has long been recognized as one of the important quality items in man's diet. This has been due in considerable part to the generally higher protein content of the grain than occurs in the majority of other food grains. Not to be lost sight of as we consider fertilization of the wheat crop is the basic fact that protein yield in the crop is fundamentally a nitrogen nutrition factor. Various other nutrients contribute, of course, but none with the controlling influence of N. The degree to which the soil and applied fertilizer supply this required ingredient largely determines ultimate protein level. Positional availability of the nutrient becomes a significant contributing factor, especially under dryfarming conditions where root activity from the surface downward declines as the stored soil moisture is progressively depleted. Other environmental factors may contribute substantially to protein percentage, with the usual observation that as N is nominally available and all supporting conditions otherwise are optimum for yield, protein content is minimal and conversely.

Studies reported by Johnson (4) indicate that increased total protein of the grain associated with added fertilizer N is no assurance of a better quality product for man. He notes a declining proportion of lysine among the amino acids as protein percentage increases from N fertilization, a matter of no concern to ruminants but troublesome to monogastric animals including man. Other studies on biological value of plant proteins have stressed the importance of sulfur-containing amino acids, perhaps exceeding the significance of lysine when nutritional value of a given food product from different sources is investigated. Unanswered is the question in-how-far the essential amino acid index (EAA) of wheat at high levels of N nutrition might be improved by enhancement of the crop's S nutrition status during the critical stages of protein accumulation and storage.

The time of N fertilizer application can have substantial bearing on crude protein in the grain of the finished crop. Most studies with winter wheat have indicated a progressively higher protein percentage with delay in time of N application, so long as moisture was received to carry the delayed application to the root system or when the N was applied foliarly, to the point where the total expressed N effect was on protein and not at all on yield.

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