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SOIL FERTILITY
and the
QUALITY OF SEEDS

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A Report on Department of Soils
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"Minor Soil Elements"

Soil Fertility and the Quality of Seeds

ROBERT L. FOX AND WILLIAM A. ALBRECHT*

INTRODUCTION

The influence of soil fertility on the quantitative aspects of plant growth is well known since the production of dry matter by plants is the criterion by which soil fertility is usually assessed. However, measurements of yield alone (as weight or volume) leave something to be desired, when yield alone does not necessarily indicate the ability of the plant to perform the reproductive and other functions for which it was intended. Soil fertility is now recognized as a factor influencing such diverse properties as the quality of forage and seed crops, and the milling and baking qualities of grains. Up to this moment, little attention has been given to the possible modification of seed germination and seedling development that results according to the level of nutrition which was a part of the environment of the parent plant.

The seeding of crops, one of the major items of labor and expense to the farmer, is often a failure. Often no satisfactory reasons for seeding failures are available. It is interesting to postulate that the causes of many such failures, especially those attributed to "damping off," may be traceable to seeds which, although normal in appearance, may be so deficient in some "vital" quality as to render them incapable of producing vigorous seedlings.

The hypothesis proposed for test is stated in three parts:

1. Soil fertility has an influence upon the elemental composition of seed.
2. The chemical and biochemical composition of the seed influences the cellular metabolism of the germinating embryo.
3. The metabolic activity of the seed and the nutrients available to the germinating embryo are factors in the germination of the seed and in the seedling vigor.

EXPERIMENTAL METHODS

To test the proposed hypothesis, some seeds of wheat grown in field plots under various specific levels of soil fertility were subjected to tests

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of germination and seedling vigor. Determinations were made of the compositions and weights of seeds and embryos. The activities of two enzyme systems and properties related to respiration were estimated.

Wheat was grown in field plots at locations in central and southeastern Nebraska and in central and southeastern Missouri. Soil treatments differed at the various locations according to the potentials of plant nutrition there. In central Nebraska, nitrogen was the fertilizer element used. In southeastern Nebraska, nitrogen and phosphorus were used; at the Missouri locations, soil treatments included, in addition, calcium, magnesium, sulfur, potassium and trace elements.

Seedling vigor, or the "germinating power" of Nadvornik (9) #, was determined by planting seeds in sterile quartz sand. The depth of planting was three inches for the initial studies, but in later work this was reduced to two inches. After incubation in a constant temperature (20° C.) chamber, the numbers of plants which had emerged at various time intervals were determined. The moisture content of the sand was supplied according to the formula given in USDA Handbook No. 30. (8)

An "index of seedling vigor" was devised to aid in the presentation of bulky data. This value was calculated by dividing the sum of the seedlings visible at each time of counting by the number of seedlings which were visible at the final count, and multiplying by 100. High values for the "index of seedling vigor" indicate early emergence.

Two estimates of respiration were obtained. Oxygen utilization was determined by means of the Warburg apparatus, and an estimate of carbohydrate respiration was made by a simple test devised for these experiments. The oven dry weight of seeds, before and after germination, was determined and the loss in weight of the seeds was taken as an indication of respiration.

Phosphatase activity was determined in homogenates of wheat sprouts which had been grown under standard conditions. The method followed was essentially that used by Sommer (11). Phytase activity was estimated by the amount of phosphoric acid liberated when seeds were germinated for various periods of time. The method of Fontaine *et al.* (4) was used with slight modifications.

Wheat embryos were excised for chemical analysis, using the method described by Brown and Morris (1).

Details of the methods used for the various chemical and biological determinations are given by Fox (5).

RESULTS AND DISCUSSION

Studies of seed quality indicate that seedling development is influenced by the nutritive environment by which the parent plant of the seed

#Numbers in parenthesis refer to citations in the Bibliography.

was grown. It is not possible to predict the nature of the seedling's response from a knowledge of only the nutrients applied through a fertilizer. The level of nutrition contributed by the soil and climatic conditions under which the seed was grown are also important factors for consideration. Likewise, balanced nutrition of the parent plant was indicated as being an important factor in determining the seed's quality.

Germination and Seedling Vigor

Nitrogen: Preliminary studies of seedling vigor using paired samples of high nitrogen and low nitrogen wheat grown in central and south-eastern Nebraska indicated that emergence of seedlings was improved when the nitrogen of the grain was increased. Nine paired samples were used in this study. A summary of data from these experiments is given in Table 1.

TABLE 1 -- EMERGENCE OF WHEAT SEEDLINGS ACCORDING TO THE CRUDE PROTEIN OF THE WHEAT GRAIN USED AS SEED. (Data given as percent)

Crude Protein		Emergence*		
		6 days	10 days	21 days
High protein wheat	14.4	15.6	92.0	91.0
Low protein wheat	11.0	10.7	85.3	85.7
Difference	3.4	4.9	6.7**	5.3

*Emergence through three inches of quartz sand.

**Just significant at 5% level $t = 2.389$.

In these tests the samples of wheat having the highest crude protein contents were outstanding because of the green color and vigor of the seedlings (Figure 1). Subsequent experiments using wheat grown at

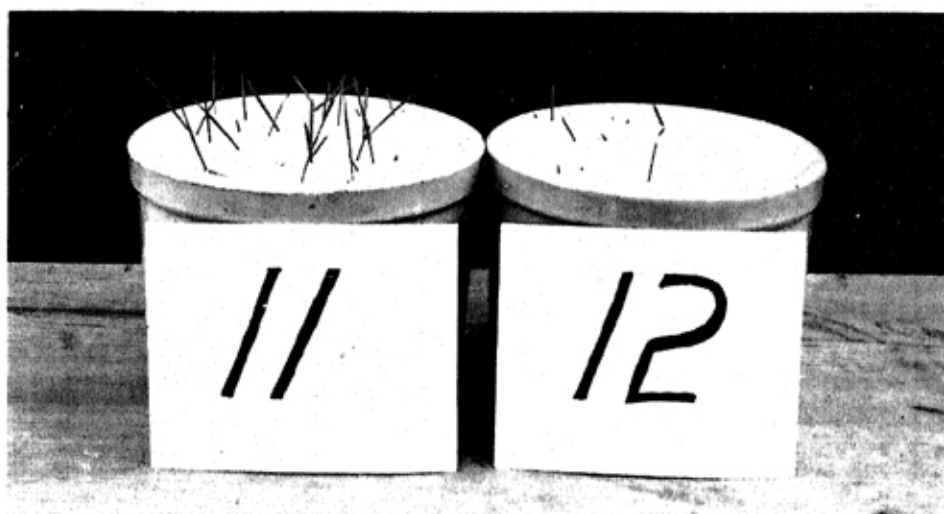


Fig. 1—Emergence of wheat seedlings from high and low protein wheat. North Platte, Neb., 1950. Treatment 11—15.7% protein; treatment 12—9.5% protein.

North Platte, Nebr., under unfavorable moisture conditions (dry, hot winds) indicated that varying levels of nitrogen moved into the grain from urea spray affected seedling emergence adversely (Figure 2). This effect was not evident when the nitrogen content of the seed was increased through applications of ammonium nitrate to the soil (Figure 3).

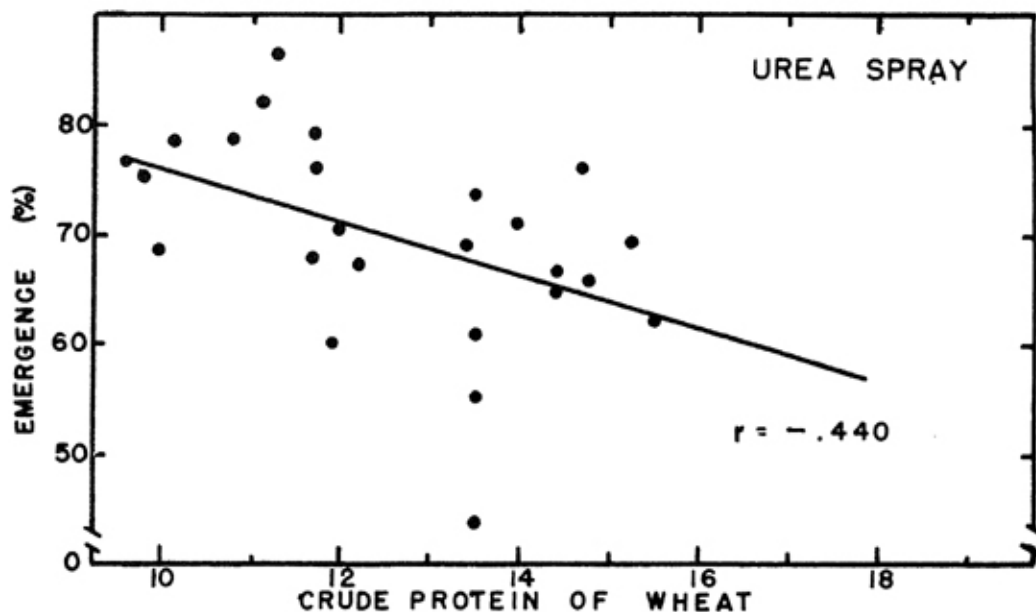


Fig. 2—Emergence of wheat seedlings from grains of various protein contents. Nitrogen applied as urea spray.

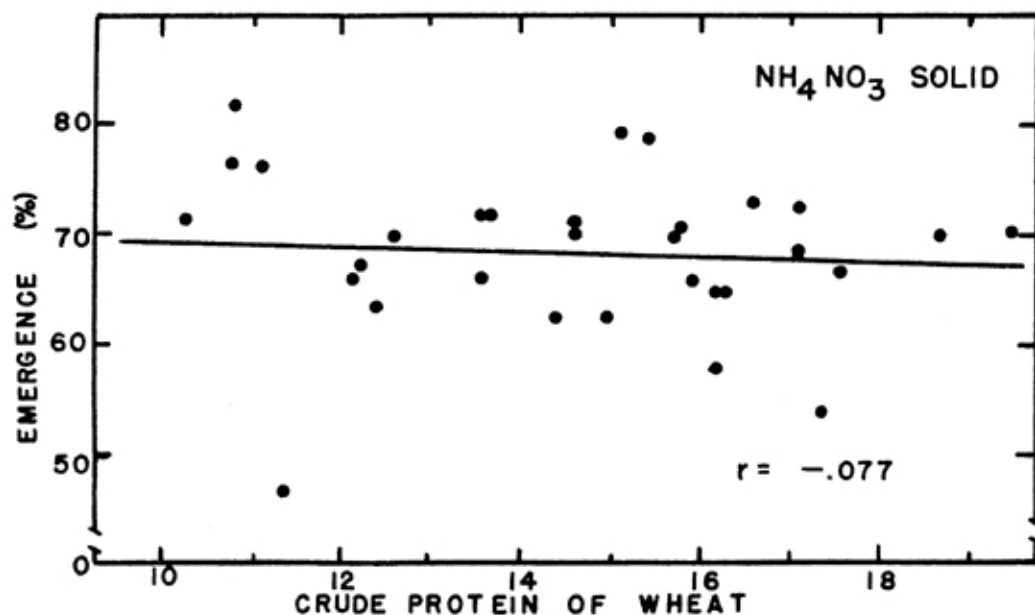


Fig. 3—Emergence of wheat seedlings from grains of various protein contents. Nitrogen fertilizer applied as ammonium nitrate.

Wheat from nitrogen fertilized plots gave improved seedling emergence at two locations in eastern Missouri.

Phosphorus: An important role for phosphorus was indicated by the effect of this element as a fertilizer on the emergence of wheat seedlings. When this nutrient was deficient in the soil, the use of moderate amounts of phosphorus in the fertilizer generally improved seed quality as measured by seedling emergence. Higher rates of phosphorus often decreased emergence. This effect was noted especially in wheat seed produced in southeastern Nebraska (Figure 4) and the phosphorus deficient Oliver silt loam soil of southeastern Missouri (Figure 5). The starter fertilizer used on the Oliver soil had the formula 8-24-8.

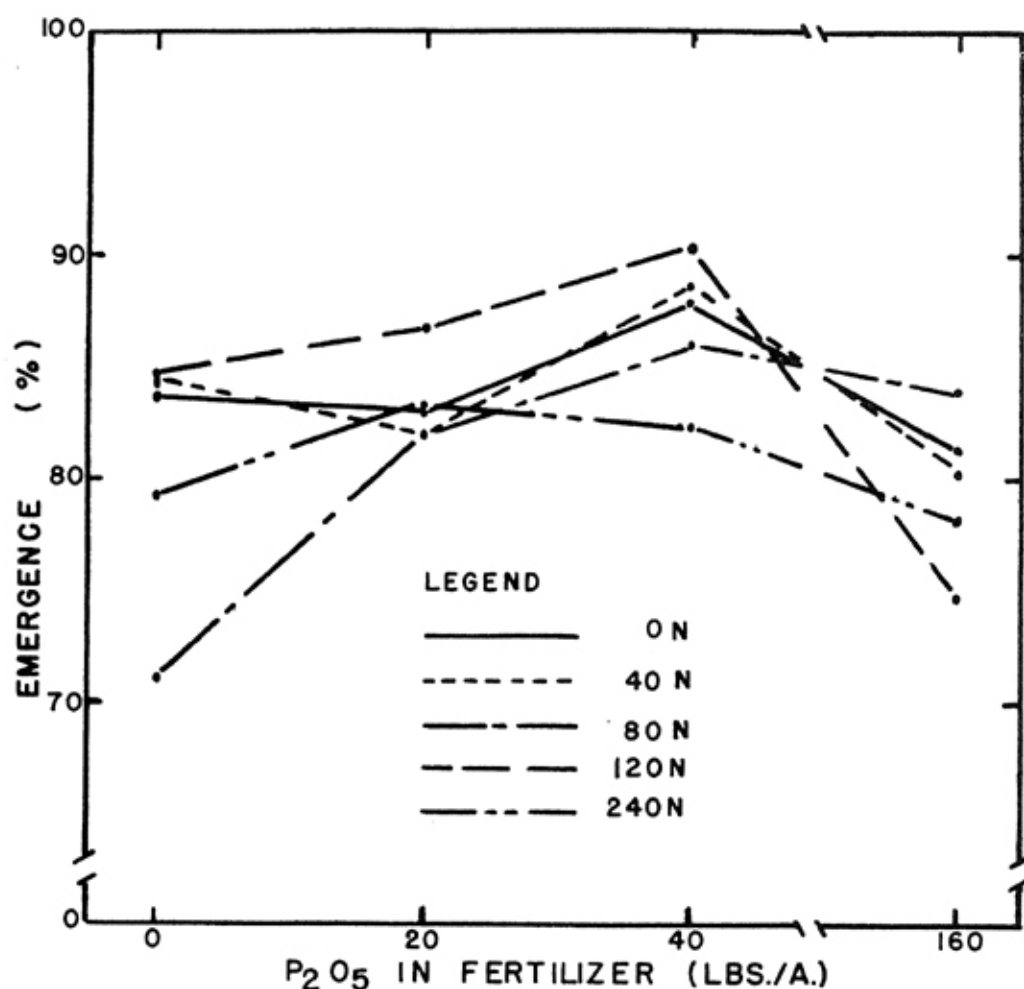


Fig. 4—Emergence of wheat seedlings through 2 inches of sand after 10 days according to the rate of nitrogen and phosphorus fertilization of the parent plants. Bennet, Nebr., samples.

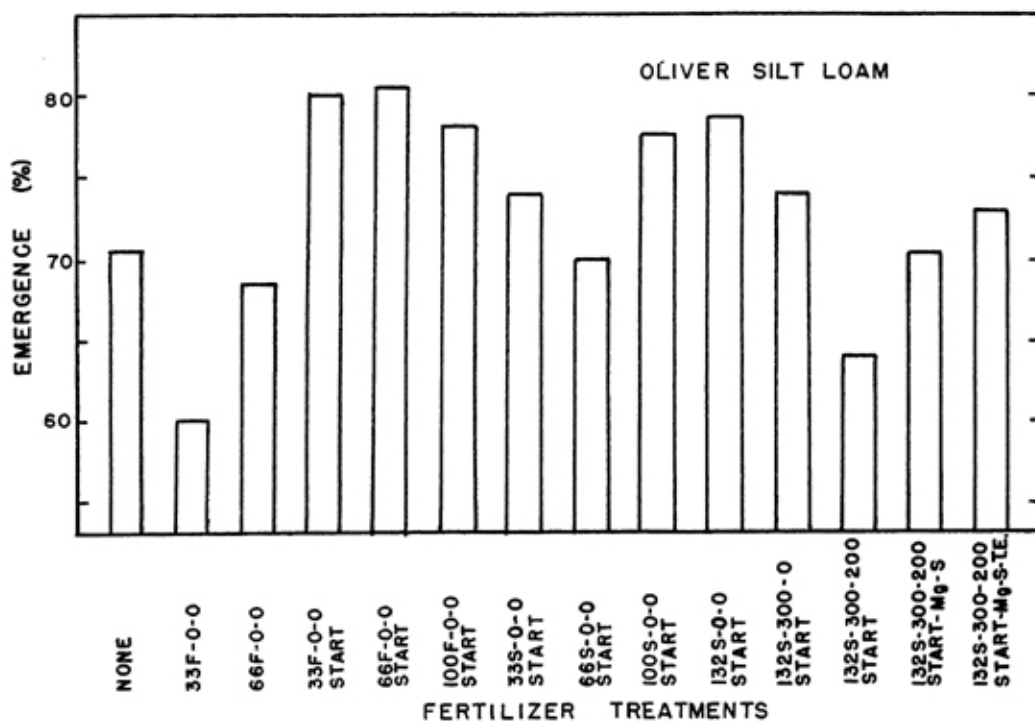


Fig. 5—Emergence of wheat seedlings through 2 inches of sand after 10 days. Seed grain produced by various fertilizer treatments on Oliver soil, southeast Missouri. F = Fall and S = Spring application.

Grain Yield: High total yield of seed grain does not necessarily indicate high quality as seed. Neither does the application of large amounts of fertilizers, including trace elements, insure good seedling emergence in wheat. Samples of wheat from Sanborn Field, Columbia, Missouri, illustrate this point. When enough nutrients were released from the soil of plot 9 (continuous wheat with no soil treatment) to produce only five bushels of wheat the result was seed of superior quality as measured by tests of emergence. Other plots which were heavily fertilized were among those samples giving the poorest emergence.

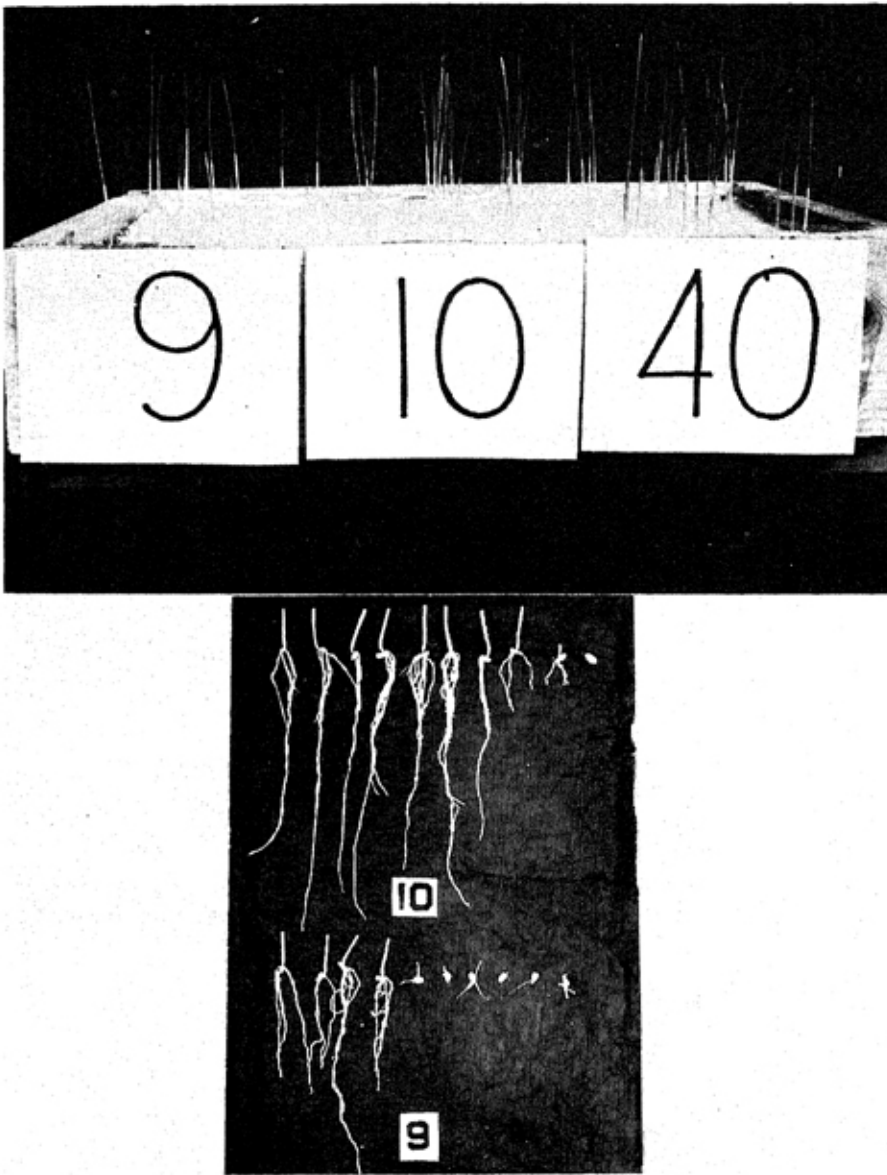


Fig. 6—Emergence and root development of wheat seedlings according to the nutrition of the parent plant. Sanborn Field, 1952. Plot 9—no treatment; Plot 10—manure; Plot 40—complete fertilizer.

In other years when the soil of plot 9 contributed even less nutrition, the effect upon seed quality, as measured by emergence, was disastrous, (Figure 6). Under these conditions, the emergence of seedlings from wheat grown on plot 9 was only 42 percent while wheat from plot 10, which also has produced wheat continuously for over 60 years, but has received annual applications of manure, gave emergence values of 75 percent.

An "index of seedling vigor" can be used to advantage for expressing the rate at which seedlings emerge. The results are tabulated for one experiment using seed produced in southeastern Nebraska in Table 2. From the data in this table, two trends can be noted: (1) nitrogen which moved into the grain late decreased the index of seedling vigor; (2) but at this particular rate of nitrogen fertilizer, the phosphorus fertilization increased the index of seedling vigor, i.e. seedlings emerged through 2 inches of sand in a shorter time.

TABLE 2 -- SEEDLING VIGOR AS INFLUENCED BY THE RATE OF PHOSPHORUS FERTILIZATION AND THE DATE OF NITROGEN FERTILIZATION OF THE PARENT PLANT. SAMPLES FROM BENNET, NEBRASKA.

P ₂ O ₅ Applied (Lb./Acre)	Date of Nitrogen Application				Mean
	Oct. 8	Apr. 25	May 7	May 24	
0	4.52#	5.31	5.39	4.77	5.00
20	5.11	5.27	5.10	4.69	5.02
40	5.17	5.25	5.19	4.69	5.06
160	5.25	5.45	5.39	4.89	5.24
Avg.	5.01	5.32	5.25	4.76	

#Seedlings visible at date of counting their emergence as percent of the total number finally emerged. (U.S.D.A. Agricultural Handbook, No. 30).

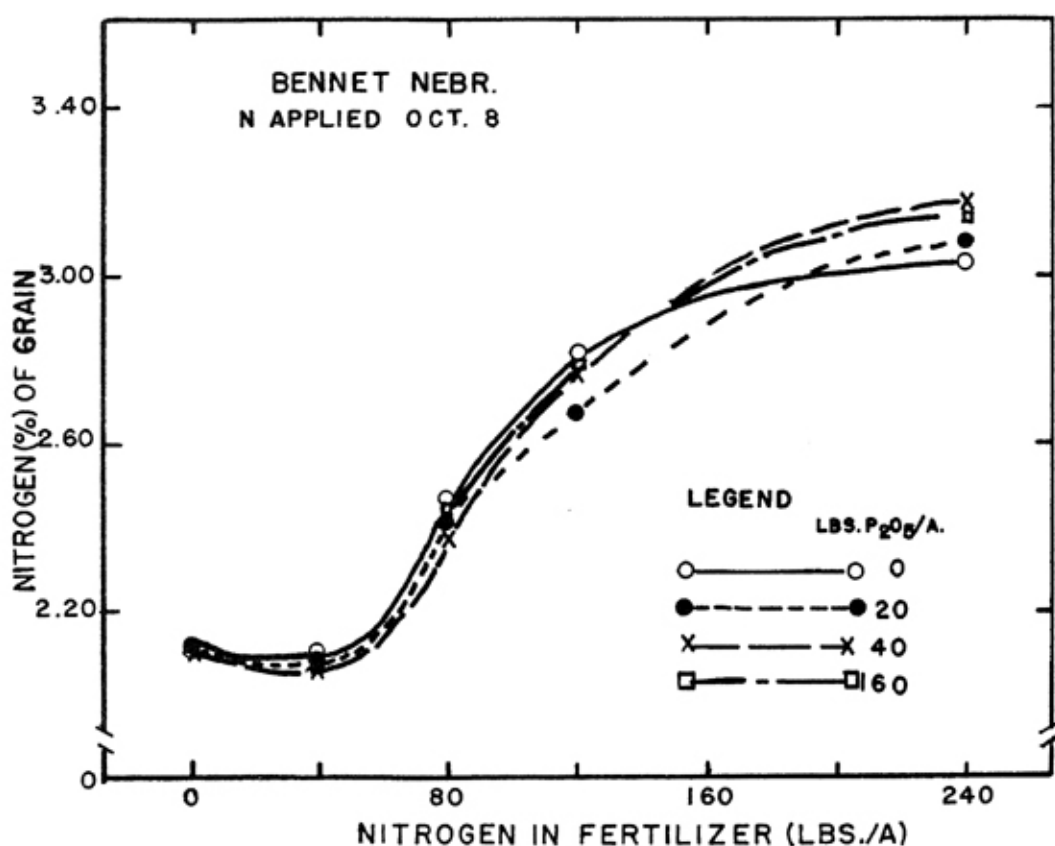


Fig. 7—Nitrogen concentration of wheat according to the rate of nitrogen and phosphorus fertilization. Bennet, Nebr.

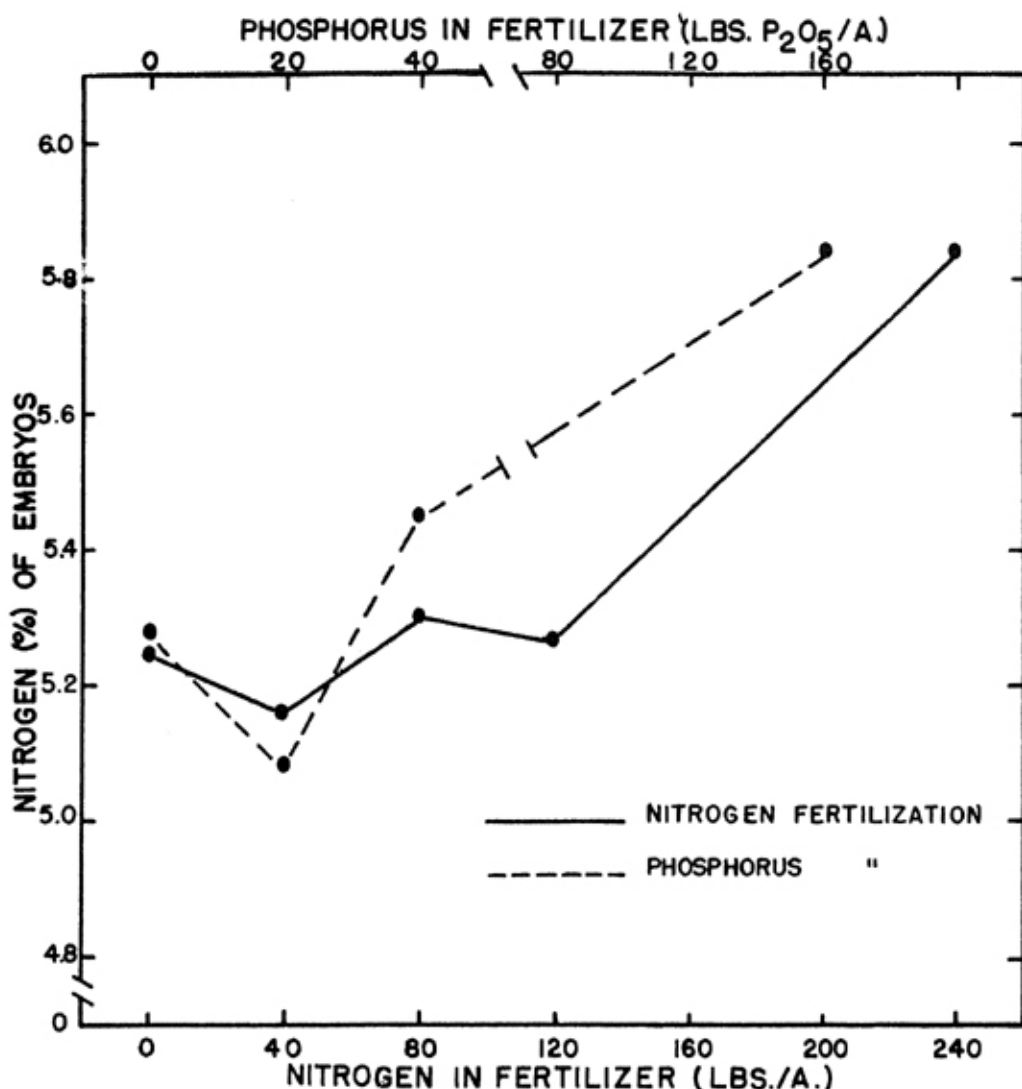


Fig. 8—Changes in the nitrogen concentrations of wheat embryos in response to nitrogen and phosphorus fertilization. Values are averages of all phosphorus or nitrogen levels.

Composition of Wheat Grain and Embryo

The germinating embryos and the developing seedlings are dependent upon the seed for mineral nutrients and energy material. The seed's chemical composition gives an indication of the total mineral nutrients available for utilization during germination. A measure of the energy material can be obtained from the seed weight since the reserves of the endosperm constitute most of the weight of the wheat grain.

In addition to its function as a storehouse for nutrient materials, the endosperm contains much of the enzyme machinery for endosperm digestion. The embryo also contains enzymes for resynthesis, into cellular components, of the products of endosperm digestion. The enzymes are

protein in nature. They are activated by various inorganic ions. Thus, seed composition, especially the nitrogen concentration, may influence the course of germination, not only by the total of nutrients present as food reserves, but also through a modification of the activity of enzymes which control plant processes. Magnesium is of interest in this capacity since, (a) it is an activator of many enzymes; (b) is relatively abundant in seeds; and (c) has been shown to influence the germination of peas (10).
Nitrogen: Nitrogen fertilization has considerable influence on the nitrogen

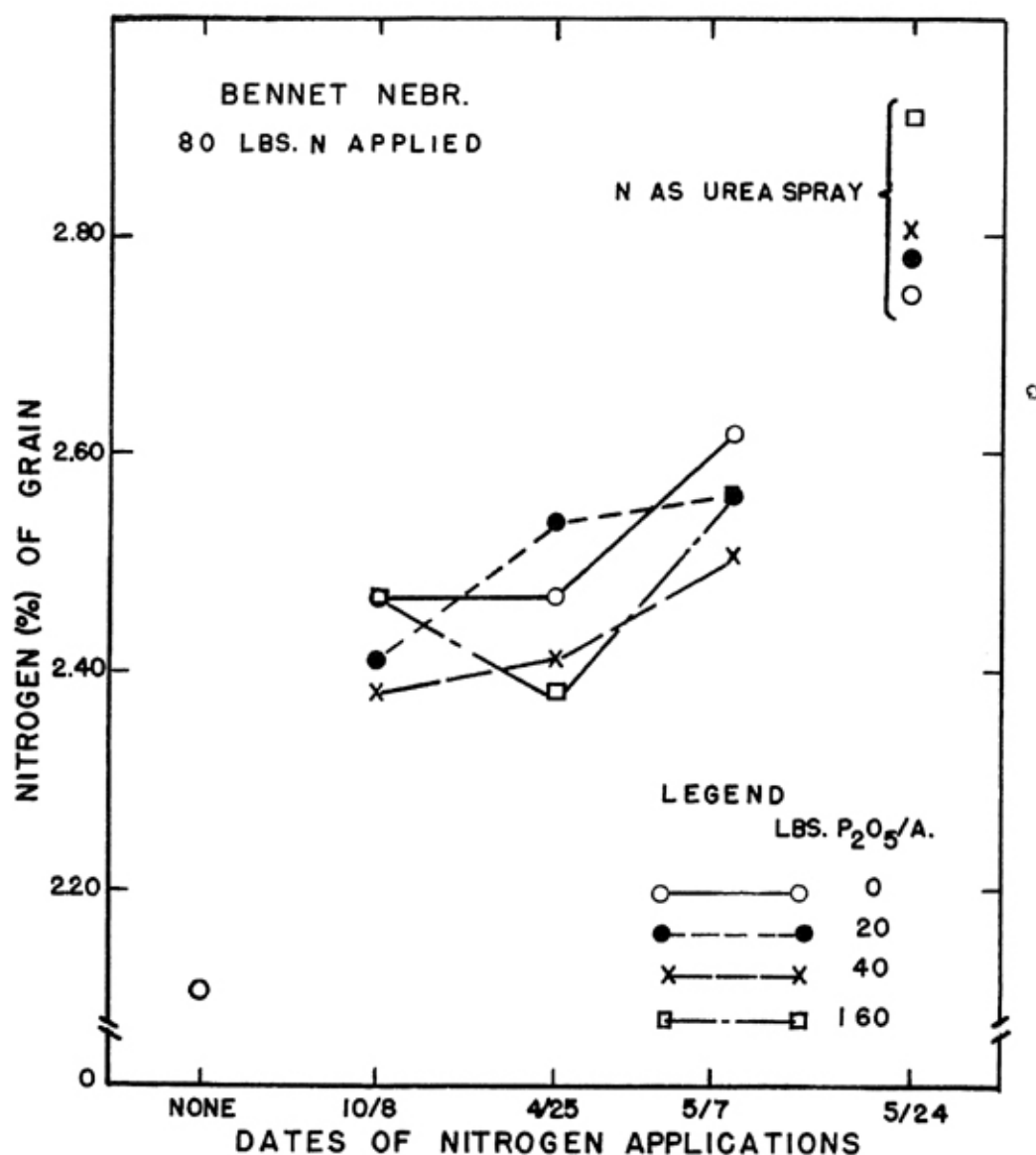


Fig. 9—Nitrogen concentrations of wheat according to the rate of phosphorus fertilization and date of application of nitrogen fertilizers. Bennet, Nebr.

composition of wheat. Relatively small effects were observed by early workers (3) but only in more recent years have fertilizers been used in sufficient quantity to permit observation of their pronounced effects on the chemical composition of the resulting grain. This influence is restricted, for the most part, to the endosperm or the storage tissue (Figures 7, 8). Small applications of nitrogen fertilizer which increase yields of grain may bring about reduced nitrogen concentration (Figure 8). Nitrogen applied at higher rates or later in the growing season served more effectively to increase the concentration of nitrogenous products stored in the endosperm (Figure 9) and to a smaller extent those in the embryo (Figure 10). Nitrogen applied on this schedule is less effective for increasing yields.

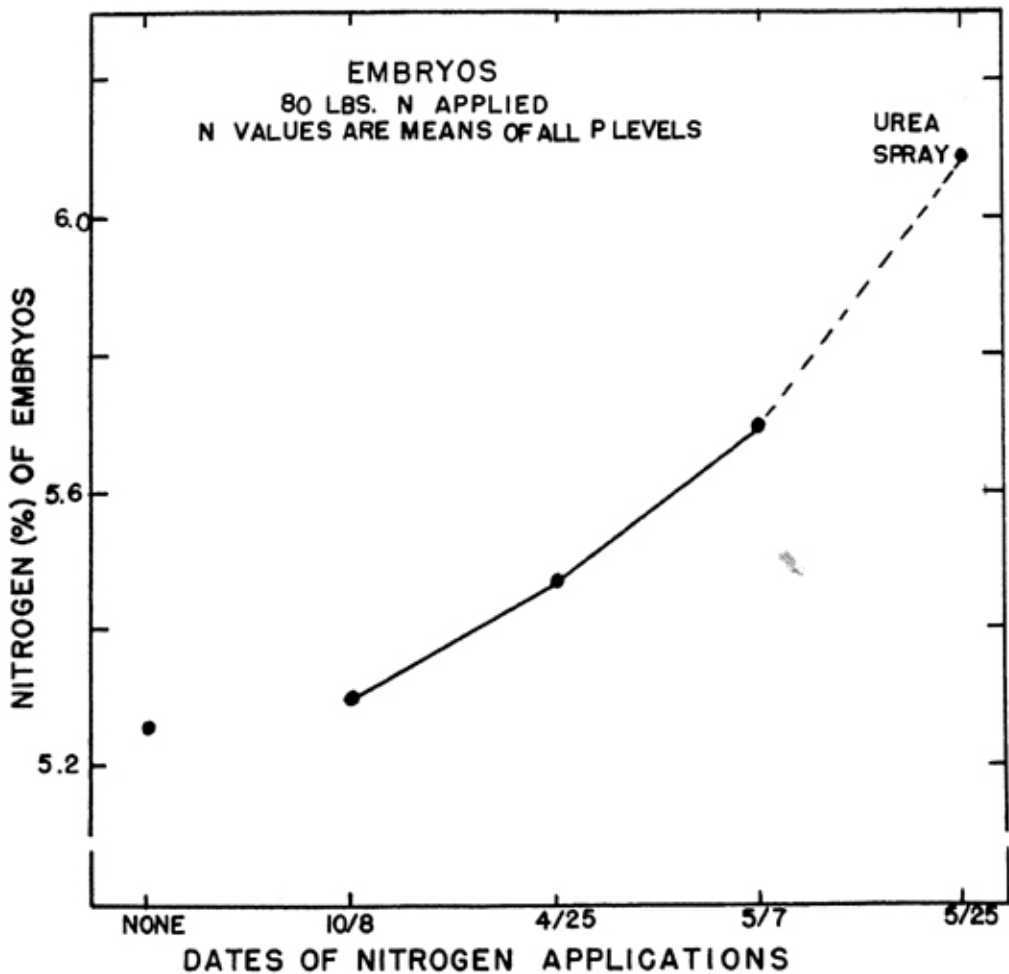


Fig. 10—Changes in the nitrogen concentration of wheat embryos in response to advancing dates of nitrogen fertilization. Values are averages of all phosphorus levels.

Nitrogen fertilization has a pronounced effect on the phosphorus content of both the whole grain and the embryo (Figures 11, 12). Davidson (2) noted this effect. He explained it as a stimulating effect of nitrogen fertilizer on growth. In contrast to the nitrogen composition, the phosphorus content of the embryo varied more than that of the endosperm. These facts are interesting since they demonstrate that, at least in some respects, the seed is subject to considerable variation; and that variations within the embryo may exceed those within the storage tissue.

Phosphorus: Phosphorus fertilization had only small effect on the chemi-

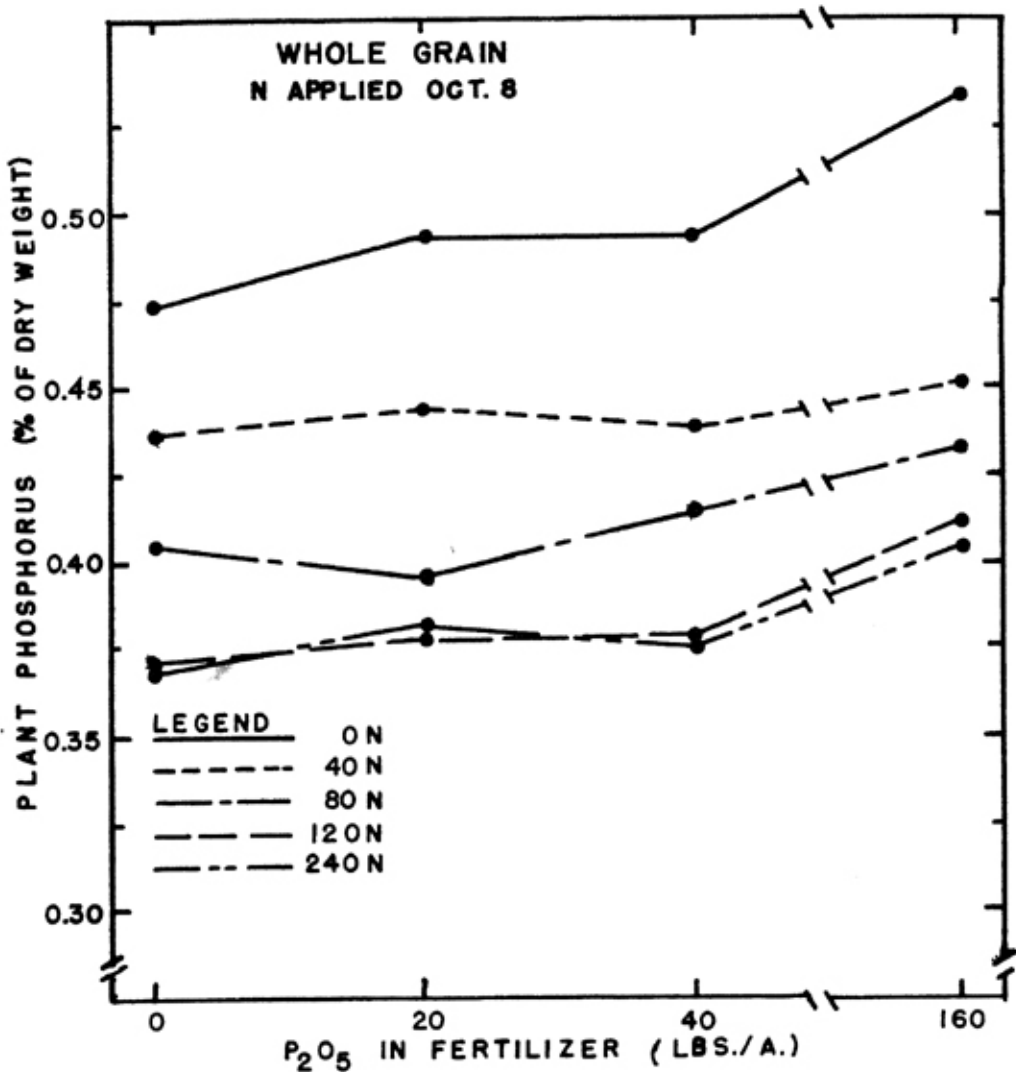


Fig. 11—Phosphorus concentration of wheat according to the rate of nitrogen and phosphorus fertilization. Bennet, Nebr.

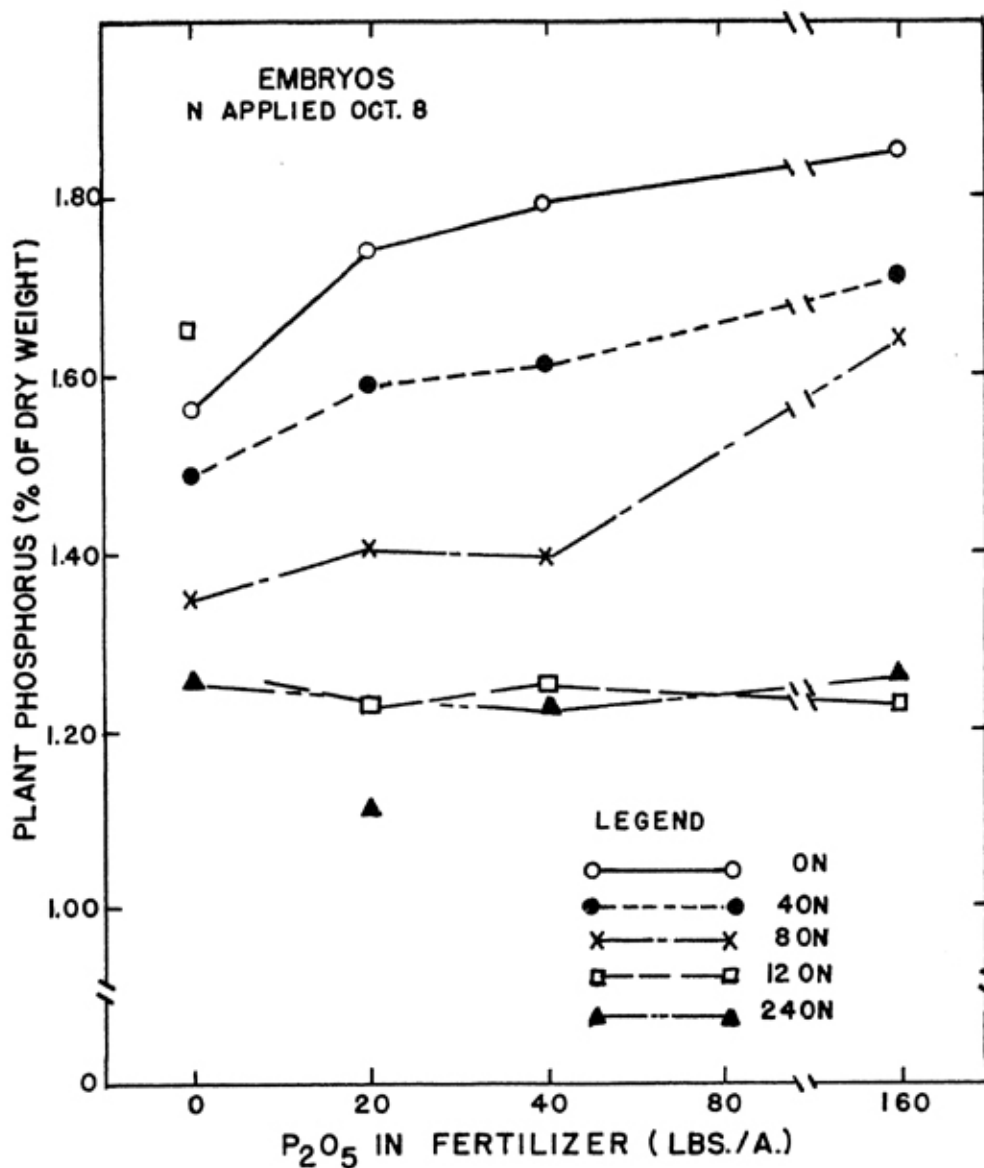


Fig. 12—Phosphorus concentration of wheat embryos according to the rate of nitrogen and phosphorus fertilization. Bennet, Nebr.

cal composition of the seed or the embryo. This indicates that the effect of phosphorus fertilizers on seedling vigor may be an indirect one.

Weight of Seeds

Weights of the seeds and the embryos were influenced by nitrogen fertilization in a manner which was unrelated to the yield of the seed grain. High nitrogen treatments, which were usually quite ineffective in

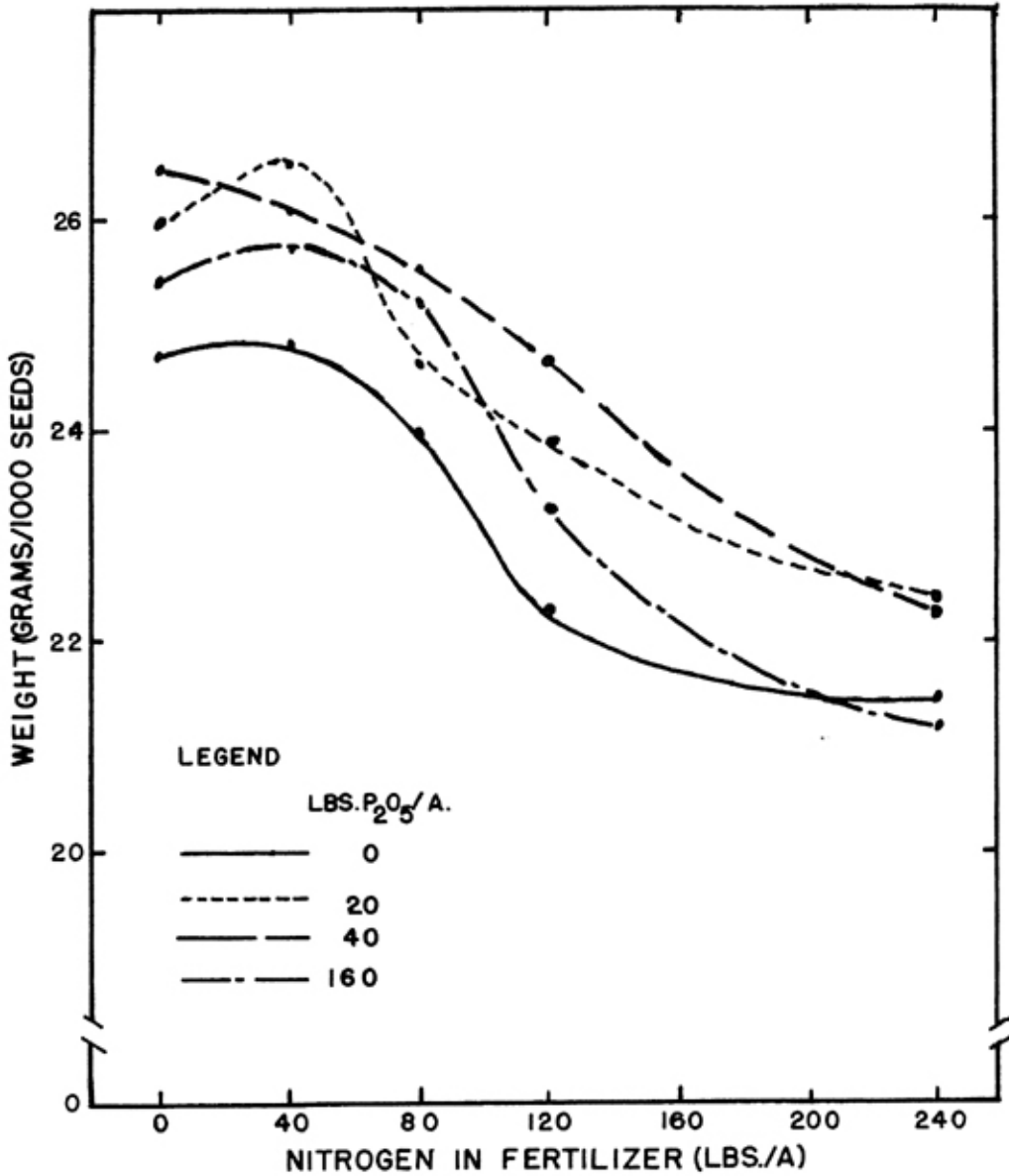


Fig. 13—Weights of wheat grain according to the amounts of nitrogen and phosphorus applied as fertilizer. Bennet, Nebr.

providing increased yields, consistently produced smaller seed than did the lower rates of nitrogen. Fertilizer treatments which increased the yield of grain did not necessarily give seed which weighed less. Thus, the higher nitrogen contents of the nitrogen-fertilized seed and the embryos were off-set, in part, by the small size of these seeds and embryos. These relationships are presented in Figures 13 and 14. High nitrogen content,

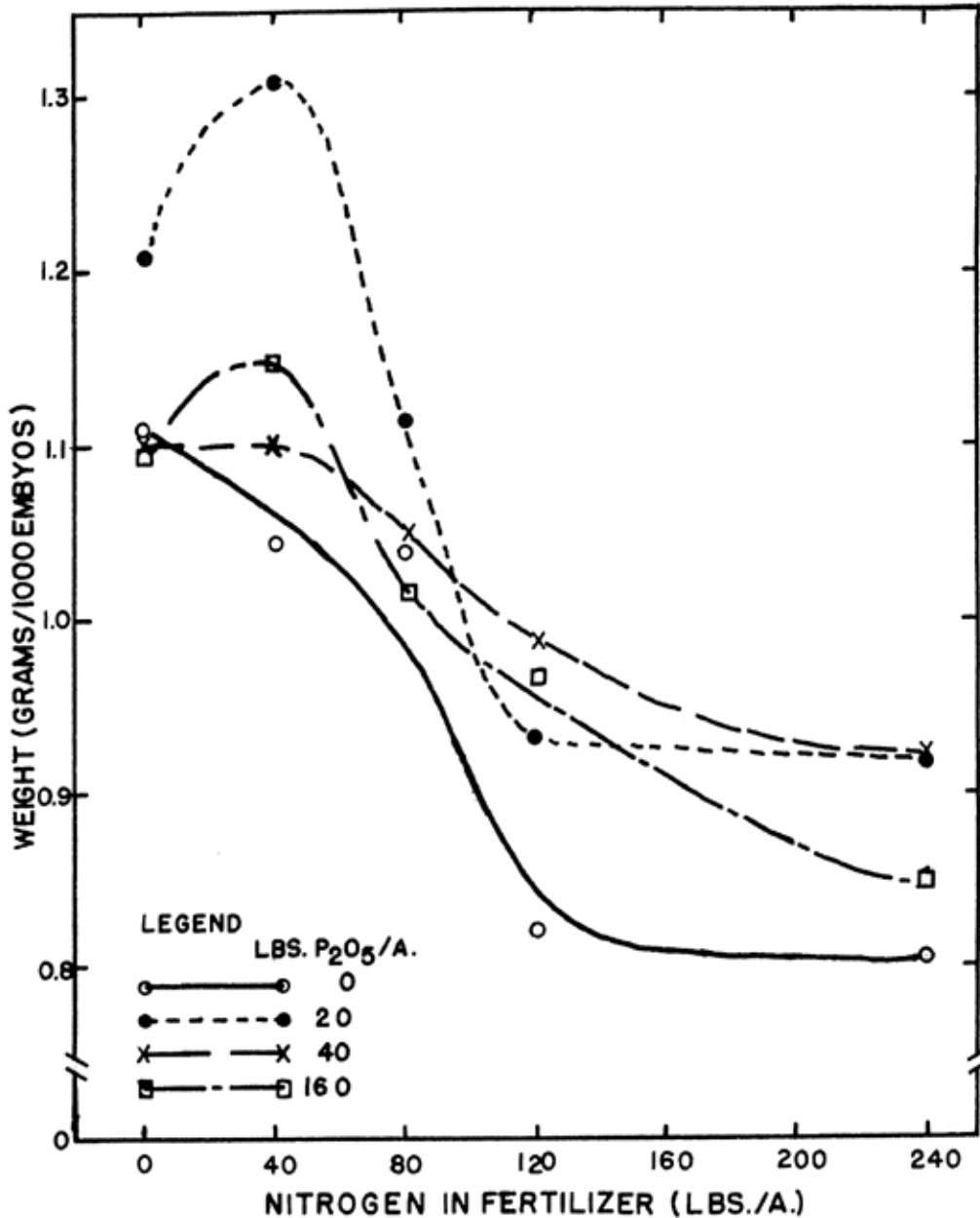


Fig. 14—Weights of excised embryos from wheat grain according to the rate of nitrogen and phosphorus fertilization. Bennet, Nebr.

low phosphorus content and small seeds were related to high levels of nitrogen fertilization. Low phosphorus and small seed were additive in their depressing effects on the total phosphorus content of high-nitrogen seed. The addition of one nutrient in large quantities may adversely affect the level of another, thus upsetting the balance which is considered necessary for normal function of metabolic processes.

The early work at Nebraska by Lyon (7) and that later by Kiesselbach (6) indicated that the weight of wheat kernels may influence the final yield of wheat. Kiesselbach reviewed the literature on this subject and found substantial agreement with the results he had obtained.

Phosphatase Activity

Measures of the release of inorganic phosphorus during germination, presumably by the action of phytase on phytin, indicated that this function is influenced slightly by seed composition. Treatments which increased yields and decreased phosphorus of the seed gave low values for phytase activity. There was a close relationship between the amount of nitrogen fertilizer applied to the wheat grain (Figure 15). Here is an in-

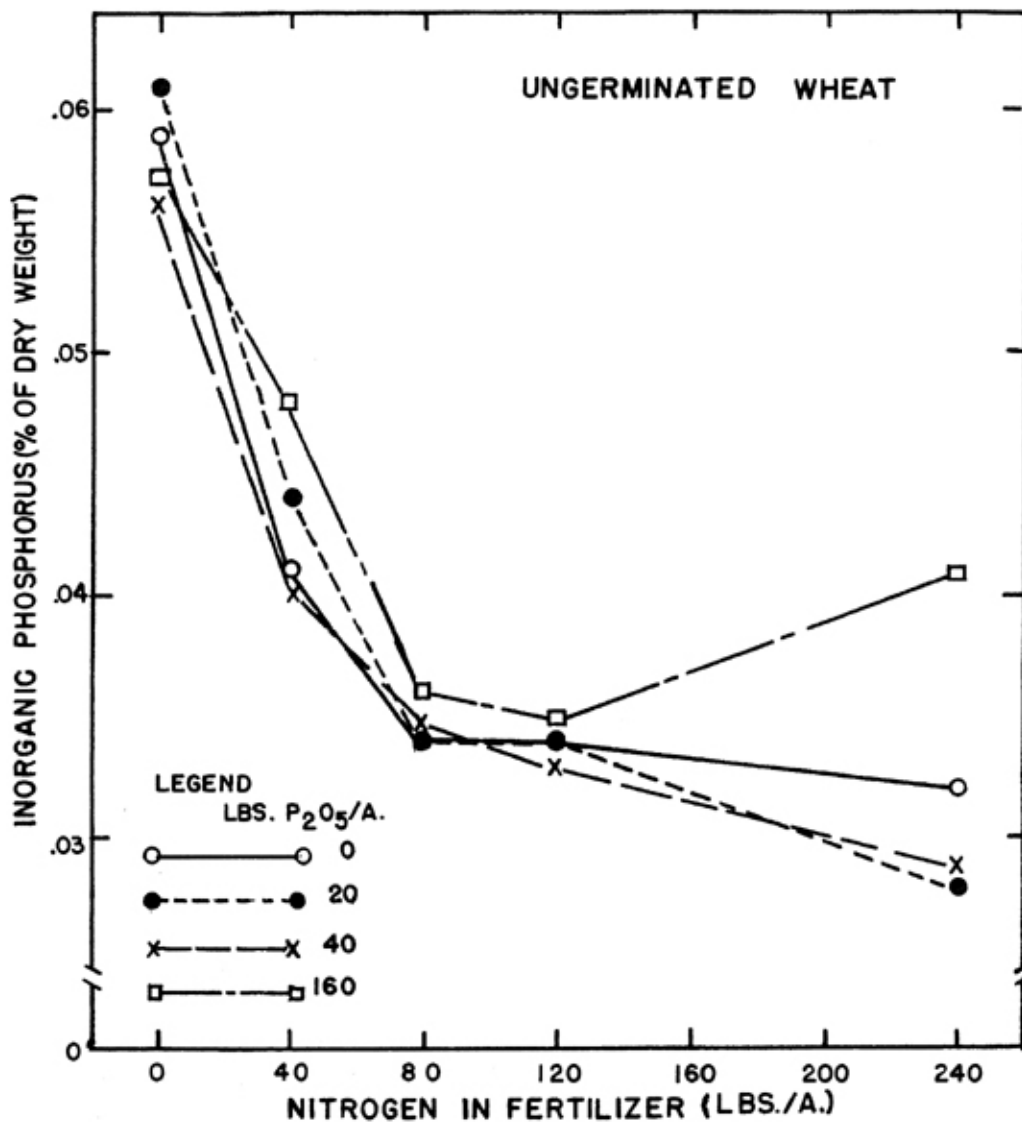


Fig. 15—Inorganic phosphorus concentration of ungerminated wheat grain according to the rate of nitrogen and phosphorus fertilization. Bennet, Nebr.

dication that improved nitrogen nutrition increased the ability of the plant to synthesize inorganic phosphorus compounds at the expense of inorganic phosphorus.

Phosphatase activity of wheat samples from Bennet, Nebraska, was increased by increasing the amount of nitrogen in the fertilizer (Figure 16). The nitrogen which reached the grain via the soil from spring (April 25) applications of nitrogen was apparently more effectively converted to phosphatase than was the nitrogen applied in the fall. Nitrogen applied on the soil on May 7 was less effective in this respect than was that applied on April 25. Evidence is presented in Figure 17 that nitrogen which was moved into the grain as a result of spraying with urea at heading

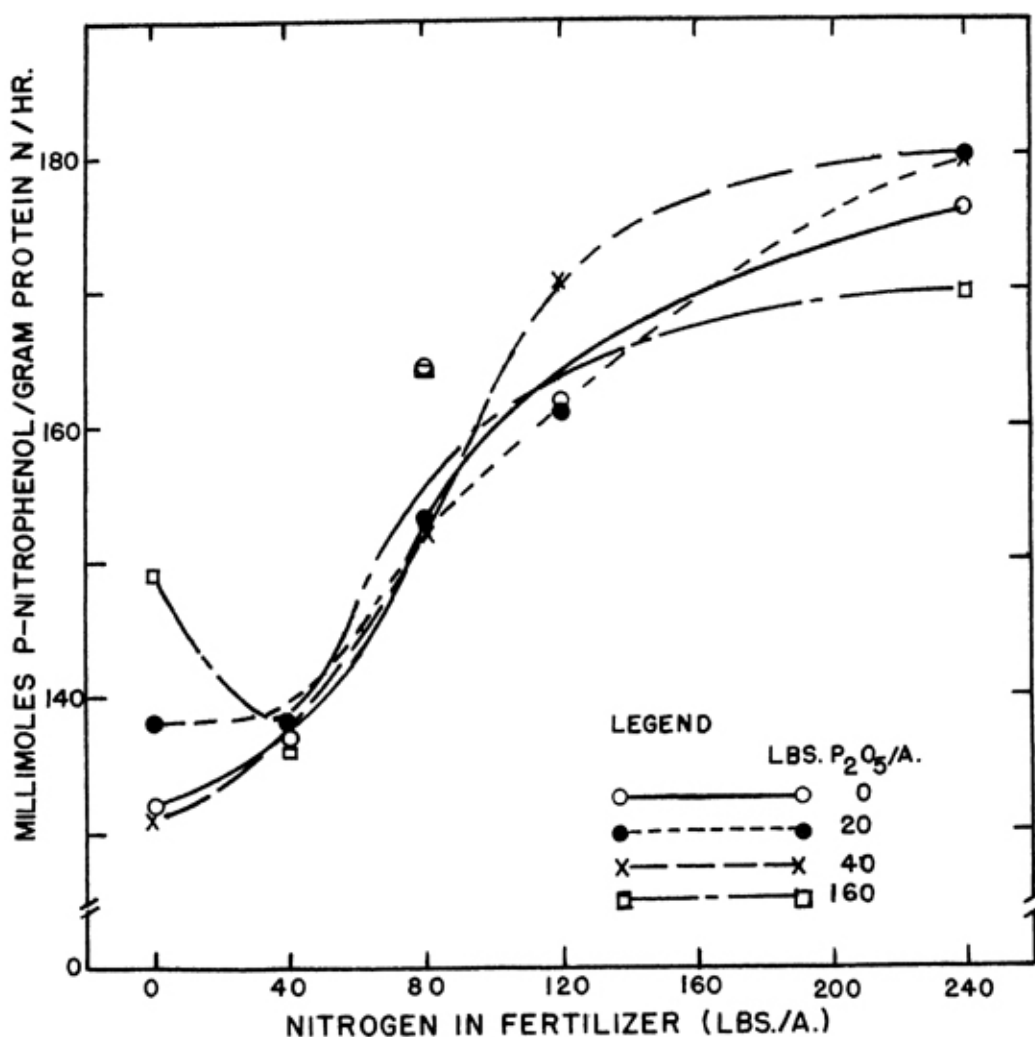


Fig. 16—Phosphatase activity of a preparation of ground wheat sprouts as influenced by the rates of nitrogen and phosphorus fertilizations of the parent plants.

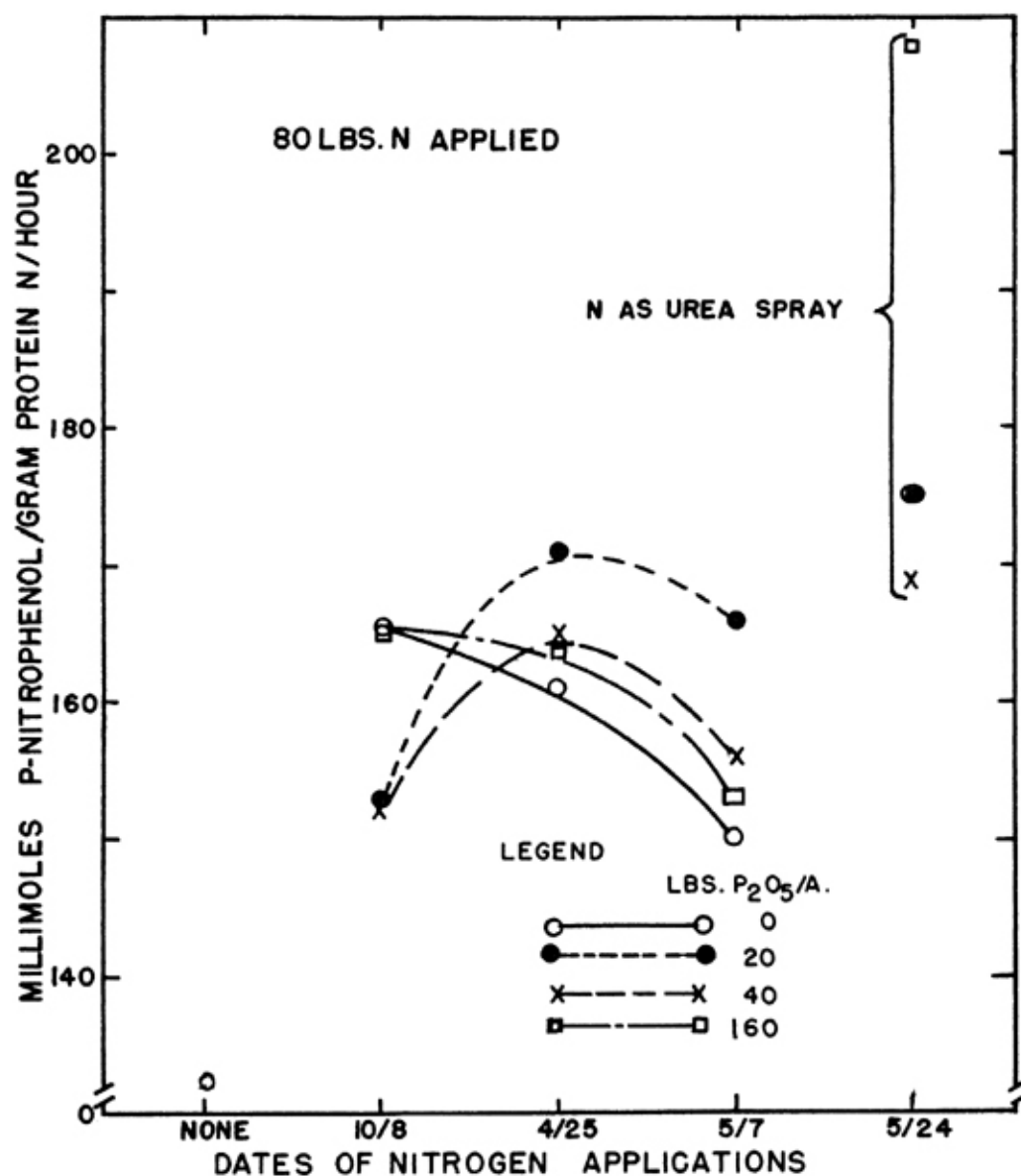


Fig. 17—Phosphatase activity of a preparation of ground wheat sprouts as influenced by the rate of phosphorus fertilization and date of nitrogen fertilization of the parent plants (as determined by the method using para-nitrophenol phosphate).

time was effectively converted into the enzyme. These results are in agreement with those of Valy and Pokary (12) who studied the effect of nitrogen nutrition on the catalase of the wheat plant, and with the work done by Virtanen (13) with bacteria. Virtanen has summarized the work of his laboratory by stating:

"... the enzymatic activity of cells depends decisively on their nitrogen content and that we have possibilities of producing low nitrogen cells enzymatically very different from normal cells. The observations made with bacteria show conclusively the decisive significance of nitrogen nutrition to the cell metabolism. Also from the point of nutrition of higher plants and animals the above results are in my opinion interesting as it can be assumed that in their cells, too, a great quantitative and qualitative deficiency of N-nutrition brings about similar changes in the enzymatic machinery of cells as in micro-organisms.

Wheat from locations in southeastern Missouri gave phosphatase activities which differed according to the treatments on the various soils (Table 3). Samples which were grown without nitrogen fertilizers were among the lowest in enzyme activity. The highest activity was associated with high fertilizer treatments.

TABLE 3 -- PHOSPHATASE ACTIVITY OF A PREPARATION OF GROUND WHEAT SPROUTS AS INFLUENCED BY THE FERTILIZER TREATMENTS BY WHICH THE WHEAT GRAIN WAS GROWN;

(Samples from Three Soils of Southeast Missouri. Values Expressed are Millimoles P-Nitrophenol per gram Protein-Nitrogen per Hour at 37.5° C.)

Fertilizer Treatment	Oliver	Menfro	Yazoo
None	158	151	170
33-0-0	168	168	182
66-0-0	178	162	174
33-0-0+starter	158	171	189
66-0-0+starter	173	178	176
100-0-0+starter	167	188	178
132-0-0+starter	178		208
132-300-0+starter	152		204
132-300-200+starter	170		200
132-300-200+starter+MgS	171		224
132-300-200+starter+MgS+Trace	182		197

Respiration

Results from studies of respiration were largely inconclusive. High-nitrogen seed utilized slightly less oxygen on a per-seed basis than did

TABLE 4 -- OXYGEN UTILIZATION AND LOSS OF ENERGY MATERIAL BY GERMINATING WHEAT SEED.

(Samples from Nitrogen-Phosphorus Interaction Experiment, Bennet, Nebraska)

Fertilizer Treatment P ₂ O ₅ (Lbs./Acre)	Oxygen Utilized		Loss of Carbohydrate
	ml/hr/10 seed	ml/hr/gm	after 5 days (% of original weight)
0	73.3	267.5	12.6
20	66.4	234.6	11.4
40	74.9	268.4	11.8
160	75.9	273.0	11.8
N (Lbs./Acre)			
0	76.1	264.2	11.6
40	78.4	260.5	12.5
80	71.1	255.7	11.3
120	69.9	255.1	12.5
240	67.7	270.8	11.6

low nitrogen seed; but oxygen utilization was greatest for this treatment when results were expressed in terms of weight. The high-phosphorus treatment gave a slightly higher value for oxygen utilization than did other phosphorus treatments. These results presented in Table 4, seem to indicate that seed composition has little influence on the enzyme systems which are involved in the respiration of energy materials.

SUMMARY

Wheat was harvested from plants which were grown with varying levels of applied nutrients on soils which represented a range in degree of soil development according to the intensity of climatic forces. Seeds were tested for their ability to germinate and for the vigor of their seedlings. Certain attributes were measured which may influence seedling performance.

Seedling vigor was influenced by the fertilizer supplied to the parent plant. There was evidence that climatic factors modified the effect of nitrogen fertilization. During a favorable year, seedling emergence was improved when the nitrogen content of the seed increased. This effect was not evident, or was even reversed, during an unfavorable year. Moderate amounts of phosphorus improved seedling emergence but large quantities of this nutrient depressed it. There was evidence that fertilization for high yields may not give seeds which are highest in quality. Seed which came from plants fertilized with large quantities of major nutrients, and trace elements in addition, often were among the lowest in giving vigorous seedlings. The importance of balanced nutrition was indicated.

The added nutrients had an important influence on the composition of both the whole seed and the embryo. Nitrogen fertilization increased the nitrogen content and decreased the phosphorus content of both seed and embryo.

The higher rates of nitrogen fertilization decreased the size of both seed and embryo.

Phosphatase activity per unit of protein-nitrogen was increased by nitrogen fertilization, while less inorganic phosphorus was liberated from the seed of higher nitrogen content.

Two measures of respiration failed to indicate any important, consistent change in this process by either the nitrogen or phosphorus content of the seed.

These results indicate that certain properties of the seed and seedling performance are changed by the level of nutrition by which the seeds were grown.

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