May 28, 1959

To the Graduate Council:

I am submitting herewith a thesis written by David G. Cummins entitled "The Germination of Corn and Wheat as Affected by Various Fertilizer Salts at Different Soil Temperatures." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

W. L. Parks
Major Professor

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and recommend its acceptance:

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Accepted for the Council:

Dale Hamilton
Dean of the Graduate School

THE GERMINATION OF CORN AND WHEAT AS AFFECTED BY VARIOUS FERTILIZER SALTS AT DIFFERENT SOIL TEMPERATURES

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

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by

David G. Cummins

June 1959

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CHAPTER I

INTRODUCTION

Reduced germination of seed due to a high concentration of fertilizer salts in the vicinity of the seed at planting is becoming of increasing importance. The problem was recognized first in the Midwest under conditions of limiting moisture. The detrimental effects are magnified by the low moisture content of the soil, which increases the salt concentration in the soil solution from a given increment of fertilizer. In the Southeast under less limiting moisture conditions, damage to seed germination is becoming of more importance as higher rates of fertilizer are being applied. The continued use of old style fertilizer applicators which place the fertilizer in contact with the seed raises this problem of what fertilizer concentrations are detrimental to germination.

The purpose of this investigation was: (1) to determine the effect of various concentrations of certain fertilizers in the soil on the germination of corn and wheat, and (2) to determine the effect of soil temperature on the rates of fertilizer that can be applied without reducing germination.

CHAPTER II

LITERATURE REVIEW

Many workers have studied the effects of various fertilizer salts upon the germination of seed. The amount of injury to germination was dependent on the source and concentration of the salts in the soil solution.

The amount of injury occurring when fertilizer comes into contact with the seed is primarily dependent upon the concentration of the fertilizer salts. The concentration of the fertilizer salts in solution is dependent upon the rate of fertilizer application and the soil moisture level (10). An increase in the rate of fertilizer application, a decrease in the soil moisture level, or both, will increase the salt concentration in the soil solution (15). Reports from a number of workers (1, 10, 11, 12, 17, 24) have shown that the amount of injury to the seed or seedling is inversely proportional to the moisture level in the soil.

Salt concentration in the soil solution has a two-fold effect upon the germination of seeds: (a) the ease of water uptake and the rate of water entry into the seed is decreased; and (b) the toxic effect produced by the fertilizer. In order for the seed to obtain water from the soil, the surface force action of the soil particles or the moisture tension, and the osmotic effect due to the dissolved materials in the soil solution must be overcome. Either a decrease in soil moisture or an increased salt concentration can cause increased soil moisture stresses and result in inhibited germination (1). Excessive concentration of soluble salts in the soil solution immediately surrounding the seed may

be toxic to the seed or young seedlings. Death or injury to the seedling in this case is attributed to plasmolysis (14). Bonner and Galston (2) define plasmolysis as the loss of water from the cell in sufficient quantities to contract the protoplasm away from the cell wall. Plasmolysis can cause death of the cell. Sherwin (16) reported that the inhibition of germination was apparently not due to a direct effect of the fertilizer upon the seed, but to the influence upon the osmotic absorption of water by the seed. The addition of fertilizer to the soil causes a stimulation in the growth of fungi, which may be an important factor in the injury of seed (3, 9, 18).

Olson and Dreier (9) reported that the application of nitrogen fertilizers in contact with the seed may cause severe stand reductions. Their work showed unfavorable effects on germination with as low as 10 pounds of nitrogen per acre adjacent to the seed during periods of low moisture. According to Olson and Dreier the deleterious effect of nitrogen carriers rank in the decreasing order: calcium cyanimide, urea, nitrate of soda, potassium nitrate, ammonium sulfate, and ammonium nitrate. The damage was decreased when the fertilizer was placed separately from the seed.

Smika and Smith (17) studied the effects of urea and ammonium nitrate on germination. Rates of fertilizer equivalent to 20, 40, 60, and 80 pounds of nitrogen per acre were applied in the row in contact with the seed. At moisture tensions approaching field capacity no appreciable effects were noted until the 80 pound per acre rate was reached. Generally, the damage from urea was less than from ammonium nitrate. This was probably because urea has a higher nitrogen content

which places a lower salt concentration near the seed when applied at the same rate of nitrogen per acre.

Wolkoff (24) studied the effects of various salts upon the germination of seed. Rates of 2,000 pounds of calcium carbonate, 200 pounds of ammonium sulfate, 400 pounds of monopotassium phosphate, 200 pounds of magnesium sulfate, and 50 pounds of ferrous sulfate were used. The salts were applied in a nutrient solution. Results showed only a very limited effect on the ability of the seeds to germinate.

In work done by Coe (3), it was shown that fertilizer had a detrimental effect upon germination. Superphosphate retarded but did not prevent germination until rates above 300 pounds of 16 per cent P_2O_5 were reached. This was applied in the row in direct contact with the seed. Nitrate of soda and muriate of potash at rates of 100 pounds per acre in the row completely inhibited germination. A complete fertilizer with the analysis 2-12-2 severely impaired germination when applied at the rate of 500 pounds per acre in the row. When nitrate of soda and 2-12-2 were applied one inch to the side of the seed at rates of 450 and 800 pounds per acre, respectively, no significant effect on germination was noted.

Rost (12) conducted some experiments on the effects of superphosphate upon the germination of corn. When mixed in a 6 inch by 10 inch by 3 inch hill, concentrated superphosphate had no appreciable effect on germination until the 1000 pound per acre rate was reached. At the 2000 pound per acre rate 75 per cent of the seed failed to germinate. Application of 200 pounds of concentrated superphosphate in the row caused no serious effect on germination, but the stand was reduced at the 350 pound per acre rate.

Parker and Oliver (10) studied the effects of fertilizer placement upon the germination of seed. A 1000 pound per acre rate of 6-6-5 was used at three moisture levels. Three placements, a 1½ inch band, two inches to the side and two inches below the seed, and two inches below the seed were used. Fertilizers mixed with the soil were initially more injurious to germination than when they were placed either below or beside the seed. Injury increased with a decrease in soil moisture.

Fertilizers placed in contact with small grain seed may delay germination and emergence as reported by Guttay (5). Complete fertilizers used at rates which placed 100 pounds per acre or more of nutrients in contact with wheat seed seriously delayed or curtailed germination and emergence. When the fertilizer was placed one inch to the side and one inch below the seed, the seedling emergence on the fertilized plots was the same as on non-fertilized plots.

Sayre and Clark (15) studied the effect of complete fertilizers on the germination of seed. When applied at the rate of 600 pounds per acre, a commercial 4-16-4 fertilizer greatly reduced the germination of bean seeds planted in contact with the fertilizer band.

Germination injury varied with the kind and rate of fertilizer application as reported by Jackson (7). A complete fertilizer with the analysis of 5-10-5 had little or no effect on germination at the 25, 50, and 100 pound per acre rate. Monocalcium phosphate, calcium nitrate, nitrate of soda, ammonium nitrate, and muriate of potash retarded the germination of sorghum when applied at rates as low as 25 pounds per acre in the row. Seedling injury increased as the rate of application

increased. Ammonium nitrate and muriate of potash were very detrimental to germination at the 50 and 100 pound rate of application. Nitrate of soda was less injurious to germination than ammonium nitrate.

Tests were run by Smith (18) to determine the injurious effects of various fertilizer materials to germinating seeds. When applied directly to the seed, 200 pounds of monocalcium phosphate plus 100 pounds of calcium sulfate reduced seedling emergence the most. This was followed in order of decreasing injury by 170 pounds of 6-12-6; 200 pounds of monocalcium phosphate; 170 pounds of 6-12-6 plus 100 pounds calcium carbonate; 100 pounds of monocalcium phosphate plus 100 pounds of calcium sulfate; 85 pounds of 6-12-6; 100 pounds of monocalcium phosphate; and 85 pounds of 6-12-6 plus 100 pounds of calcium carbonate. Calcium carbonate tended to offset the detrimental effects of direct applications of the 6-12-6 fertilizer. Direct application of fertilizer to the seed weakened many of the seedlings and left them vulnerable to diseases.

Stroup (19) reported a reduction in germination from fertilizer placed in contact with the seed. Ammonium nitrate and nitrate of soda delayed emergence at the 50 pound per acre rate and severely reduced germination at the 100 and 150 pound per acre level. Muriate of potash did not affect germination at the 50 pound per acre rate, but severely reduced germination at the 100 and 150 pound per acre rate. A complete fertilizer with the analysis of 10-20-10 severely reduced germination when the 150 pound per acre level was reached; whereas, a 10-20-20 analysis fertilizer severely affected germination at the 100 pound per acre level.

Musgrave and Coe (8) reported that an application of fertilizer in the row inhibited germination of cotton. The effect was more pronounced from nitrogen and potassium than from phosphorous.

Tolman and Stout (20) studied the effect of ammonia upon seed and young seedlings. They reported that sufficient quantities of ammonia were released from dilute solutions of urea to be injurious to young seedlings and germinating seed.

Little or no literature is available on the interaction of fertilizer salts and temperature and their effect on the germination of seed. Much work has been done on the effect of temperature alone on seed germination.

Wilson and Hottes (23) studied the effects of various temperatures upon the germination of wheat. They found a temperature of 15° C. to be nearly optimum for germination of wheat. Higher temperatures of 20° and 30° C. gave more rapid germination, but lower temperatures of 10° and 15° C. gave a higher per cent germination. A high temperature made the kernel more susceptible to mold attack.

Tests by Coffman (4) showed corn to germinate best at temperatures above 10° C. with a sharp decrease in germination below 10° C. Small grains in general germinated well at temperatures as low as 3.5° C.

In studies by Wilson (22), oats and soybeans germinated equally well at temperatures of 10°, 15°, 20°, 25°, and 30° C. Wheat germinated better at 15° C. with a decrease in either direction of temperature change. The increasing rate of germination with an increase in temperature appeared to conform with Van't Hoff's law.

Toole et al. (21) found that both dark and burley tobacco germinated well at 15°, 20°, 25° C. with a slight drop at 30° C. and a great drop at 35° C.

CHAPTER III

METHODS AND PROCEDURES

The effects of various fertilizers on the germination of seed was studied in growth chambers and in the field.

The Effect of Per Cent Concentration of Fertilizer and of Temperature on Germination

Three growth chambers, each with an internal volume of 100 cubic feet and thermostatically controlled at 50°, 68°, 86° F. were used in this study. Twenty fluorescent lights, using cool white and red tubes at a ratio of 9:1 were used as the light source. Alternating periods of sixteen hours of light and eight hours of dark were maintained during the course of the experiment. Covered light bulbs were used as heat sources during the dark period. A ten-inch fan was in operation in each chamber at all times to insure good air circulation and to keep a uniform temperature. A shelf was suspended in the middle of each chamber to support the cups and flats.

Huntington silt loam soil was used in this study because its physical properties are desirable for greenhouse use. The soil moisture level was maintained at approximately 20 per cent moisture, which was about one atmosphere tension.

Urea, ammonium nitrate, nitrate of soda, ammonium sulfate, 48 per cent concentrated superphosphate, 20 per cent superphosphate, sulfate of potash, muriate of potash, and 6-12-12 complete fertilizer were studied at levels of 0, 0.01, 0.05, 0.1, 0.5, 1.0, 2.0, 5.0, 10.0, 20.0, 30.0, and 50.0 per

cent material per 2,000,000 pounds of soil. Anhydrous ammonia was applied at levels of 0, 0.0012, 0.0025, 0.0037, 0.005, 0.01, 0.025, 0.05, 0.10, 0.15, 0.25, and 0.5 per cent material per 2,000,000 pounds of soil. The fertilizer and soil were mixed in a twin-shell mixer and transferred to twelve ounce ice cream cups. Corn was planted at the rate of ten seeds per cup and wheat at fifteen seeds per cup. Each fertility level was replicated three times and studied at each of the three temperatures. Each test was completely randomized in the growth chambers. A germination count was made at the end of a fifteen-day period.

A companion study was made with the fertilizer applied in the row in contact with the seed. Corn was fertilized as follows: urea was applied at rates of 0, 15, 30, 45, and 60 pounds of N per acre; ammonium nitrate, nitrate of soda, ammonium sulfate, sulfate of potash, and muriate of potash were applied at rates of 0, 25, 50, 75, and 100 pounds of N or K_2O per acre; ordinary and concentrated superphosphate were used at levels of 0, 100, 200, 300, and 400 pounds of P_2O_5 per acre; 6-12-12 fertilizer was applied at levels of 0, 50, 100, 200, and 300 pounds of material per acre. Wheat was fertilized in the following manner: urea was applied at rates of 0, 90, 180, 270, and 360 pounds of N per acre; ammonium nitrate, nitrate of soda, ammonium sulfate, sulfate of potash, and muriate of potash were applied at rates of 0, 150, 300, 450, and 600 pounds of N or K_2O per acre; ordinary and concentrated superphosphate were used at levels of 0, 300, 600, 1200, and 1800 pounds of P_2O_5 per acre; 6-12-12 fertilizer was applied at rates of 0, 300, 600, 1200, and 1800 pounds of material per acre. The fertilizer rates for corn were calculated on the basis of forty-two inch rows and wheat on the basis of seven inch rows. The corn

and wheat were planted in twelve-inch by eighteen-inch flats with ten corn seeds and twenty wheat seeds planted per foot of row. Each level of fertilizer was replicated two times. One temperature, 68° F., was used in this phase of the study. A germination count was made at the end of a fifteen-day period.

The Effect of Various Fertilizers on the Germination of Corn Under Field Conditions

The effect of various fertilizer salts on the germination of corn was studied on Sequatchie silt loam soil at the Koella Farm in Blount County. Dixie twenty-nine seed corn was planted in mid-May 1958 at an average rate of forty-three seeds per thirty feet of row in one row plots thirty feet long. A modified split plot experimental design was used with three replications. Urea prills, urea crystals, ammonium nitrate, nitrate of soda, ammonium sulfate, muriate of potash, sulfate of potash, concentrated superphosphate, ordinary superphosphate, and 3-12-12, 6-12-12, and 10-10-10 fertilizers were used. The rates of N, K_2O, and P_2O_5 in the fertilizers applied were 15, 30, 45, and 60 pounds per acre. The complete fertilizers were applied at the rates of 100, 200, 300, and 400 pounds per acre. A germination count was made fifteen days after planting.

CHAPTER IV

RESULTS

The Effects of Per Cent Concentration of Fertilizer on the Germination of Corn and Wheat

The results of the effects of per cent concentration of fertilizer on the germination of corn and wheat are presented graphically in Figures 1 through 10. The fertilizer concentrations are presented on the basis of the per cent material in the soil and the pounds of N, P_2O_5, and K_2O per 2,000,000 pounds of soil. Appendixes A through J show the germination percentages at the different temperatures and concentrations of the various fertilizers. Table I shows the concentrations of the various fertilizers where decreased germination occurred. Each germination percentage shown is an average of three replications. The values plotted on the graphs represent the germination in per cent at 68° F. for corn and 50° F. for wheat. Corn did not germinate at the 50° F. temperature.

Anhydrous ammonia was not injurious to the germination of corn and wheat at fertilizer concentrations up to 0.05 per cent. Concentrations above 0.05 per cent were very detrimental to germination of both corn and wheat.

Urea did not depress germination at concentrations up to 0.05 per cent. The percentage germination of both corn and wheat dropped rapidly at concentrations above 0.05 per cent.

Concentrations of nitrate of soda up to 0.5 per cent had little effect on the germination of corn and wheat. Concentrations above 0.5 per cent were very deleterious to germination of both corn and wheat.

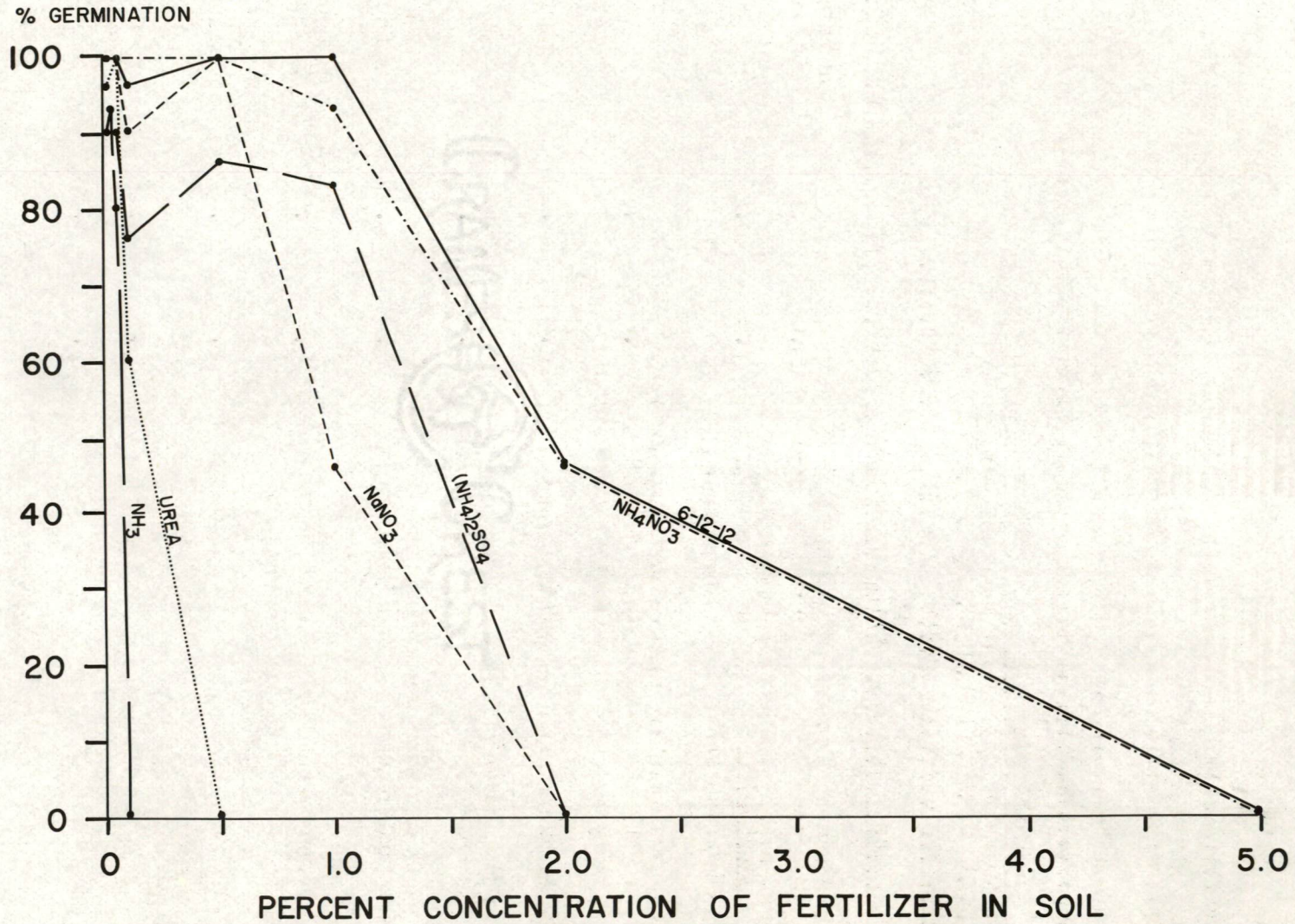


Fig. 1.—Percent germination of corn at 68° F. in a Huntington soil at different concentrations of five nitrogen fertilizers.

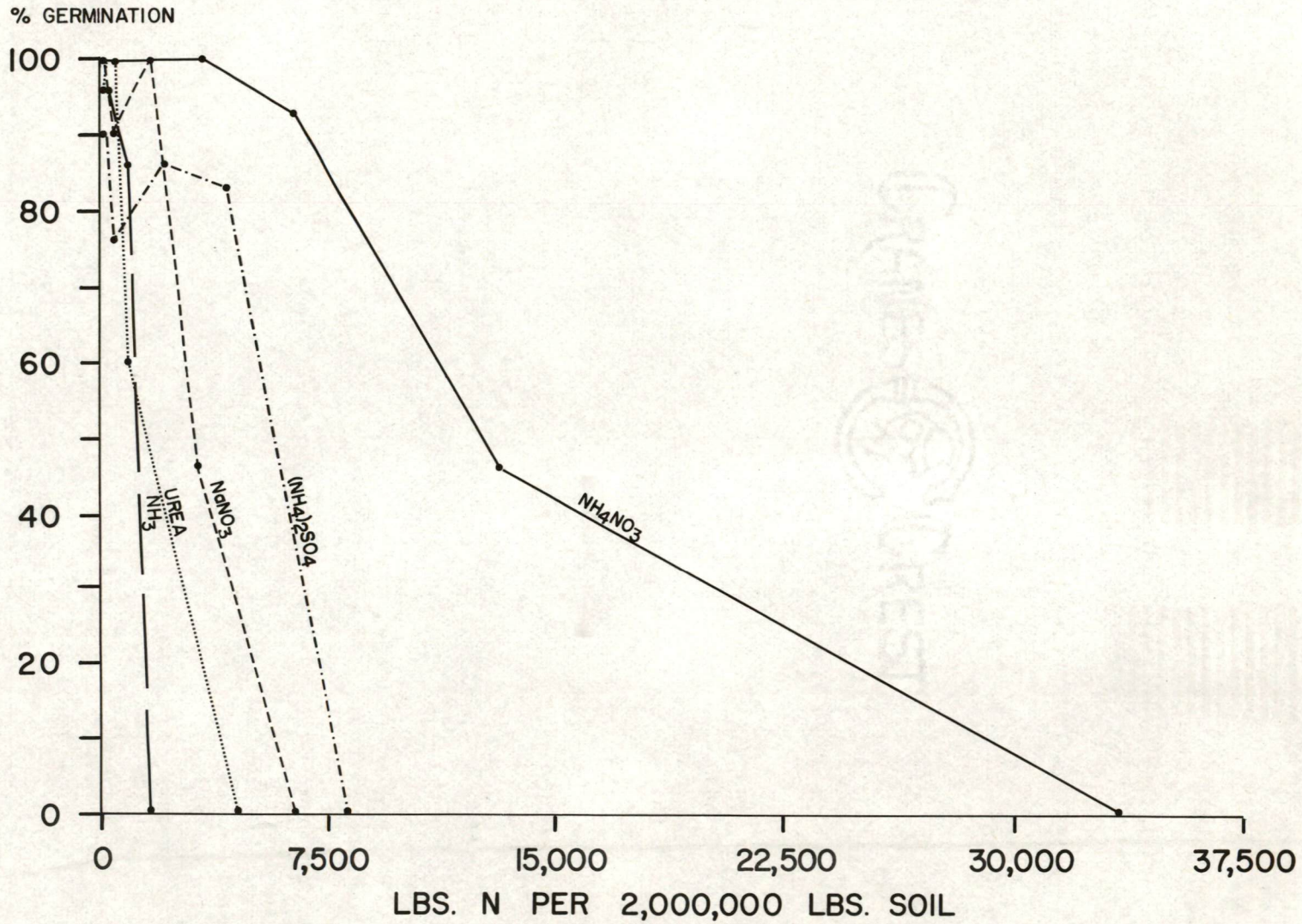


Fig. 2.—Percent germination of corn at 68° F. in a Huntington soil at different concentrations of five nitrogen fertilizers.

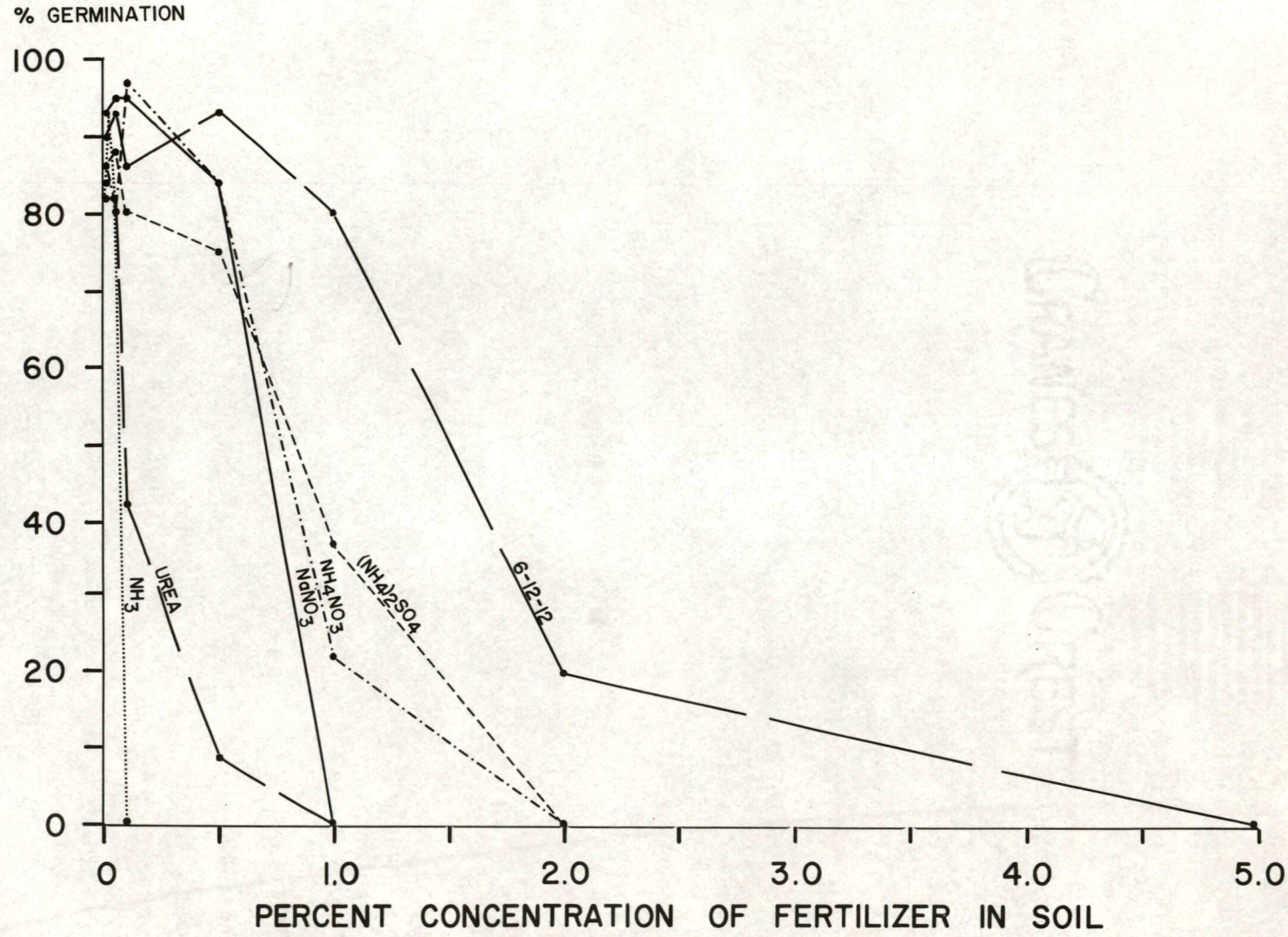


Fig. 3.—Percent germination of wheat at 50° F. in a Huntington soil at different concentrations of five nitrogen fertilizers.

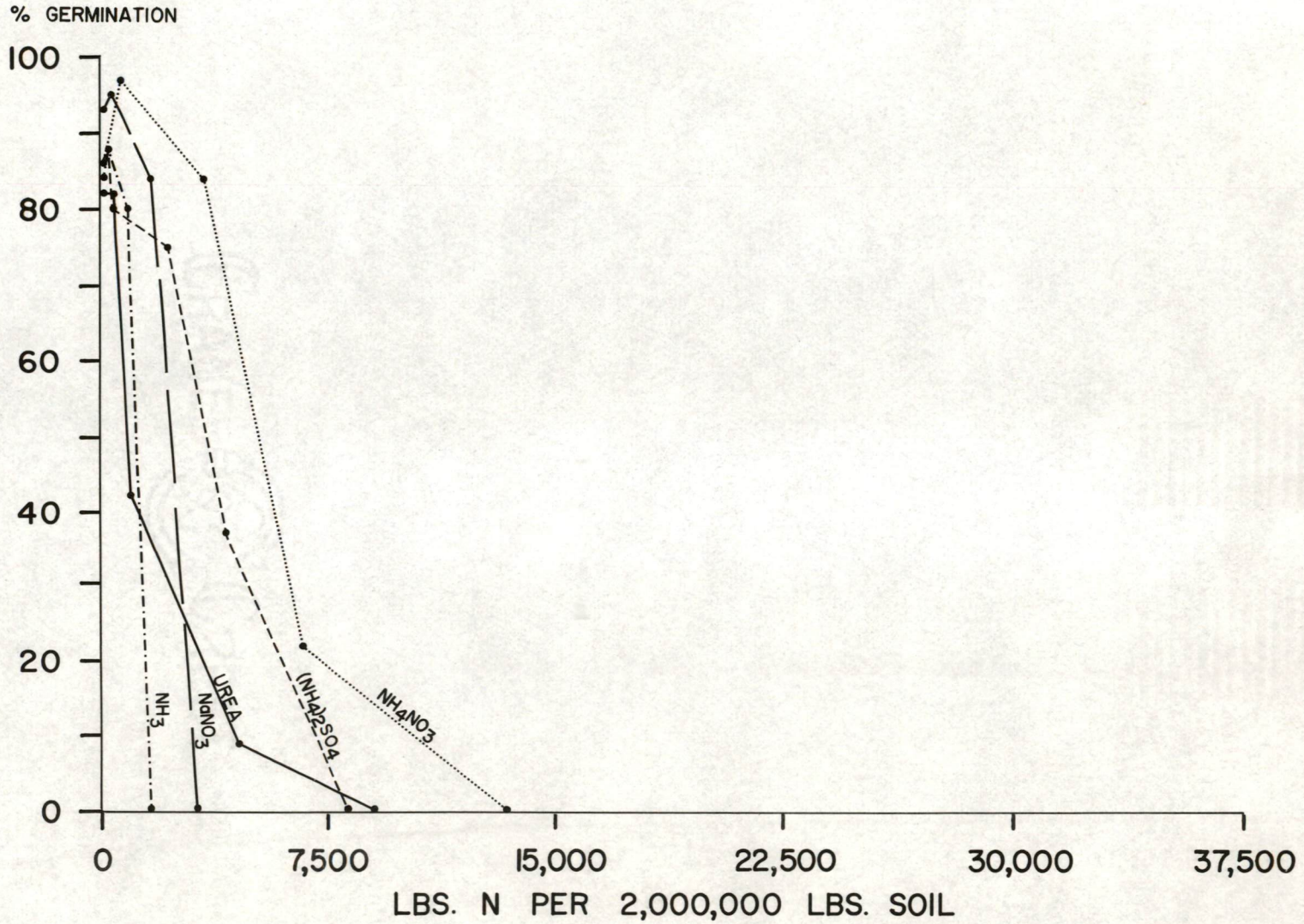


Fig. 4.—Percent germination of wheat at 50° F. in a Huntington soil at different concentrations of five nitrogen fertilizers.

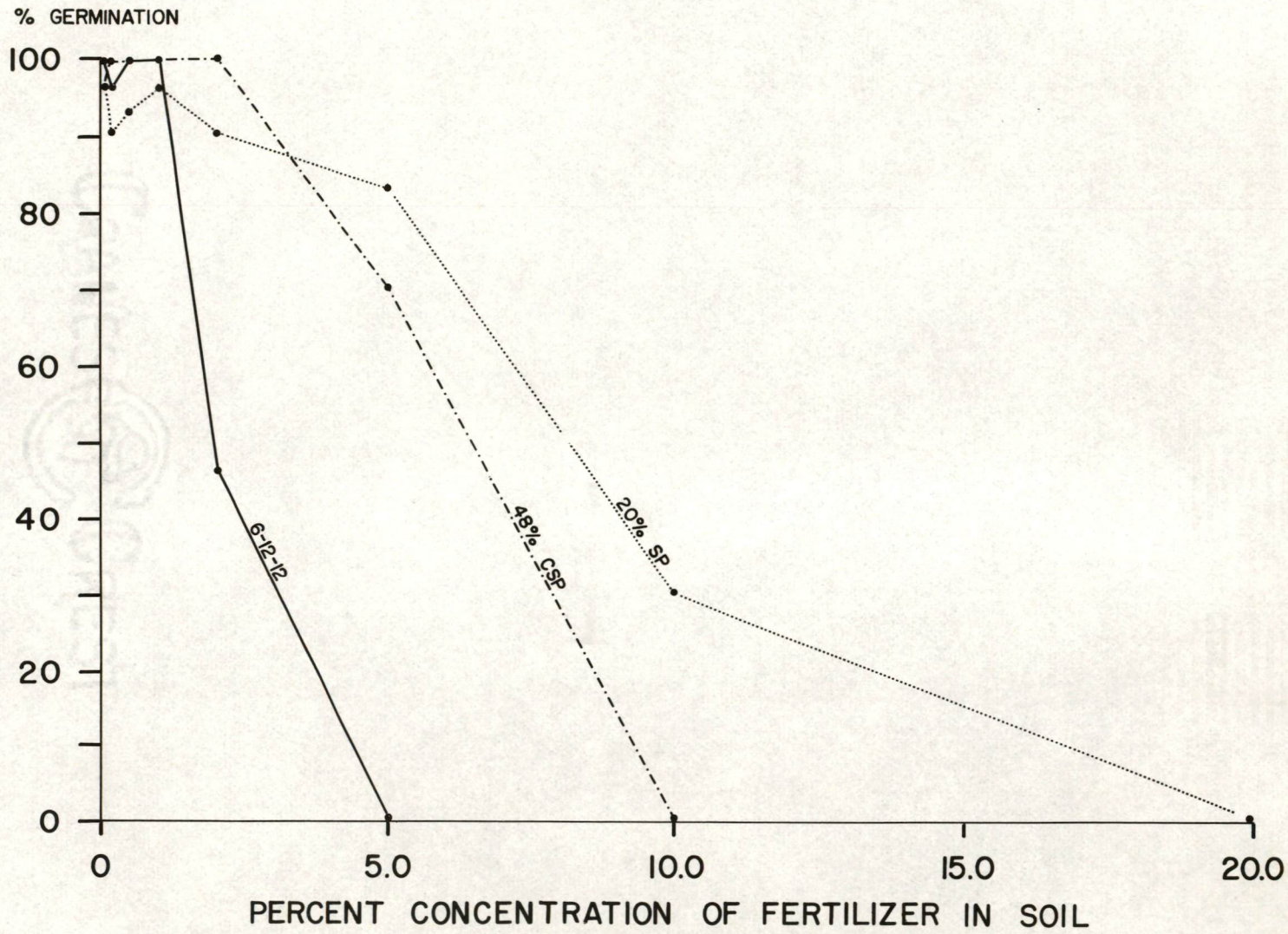


Fig. 5.—Percent germination of corn at 68° F. in a Huntington soil at different concentrations of two phosphate fertilizers.

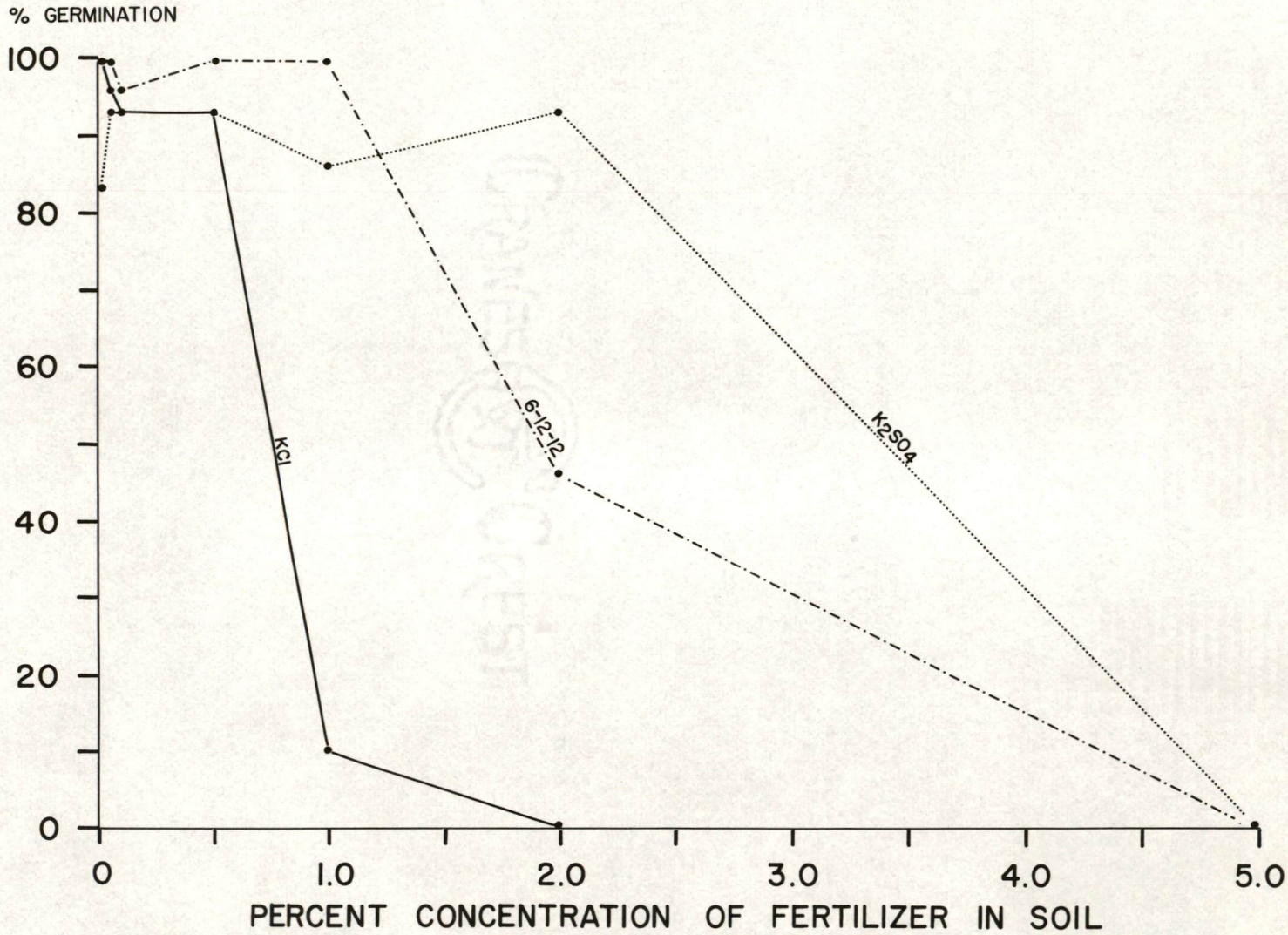


Fig. 6.—Percent germination of corn at 68° F. in a Huntington soil at different concentrations of two potash fertilizers.

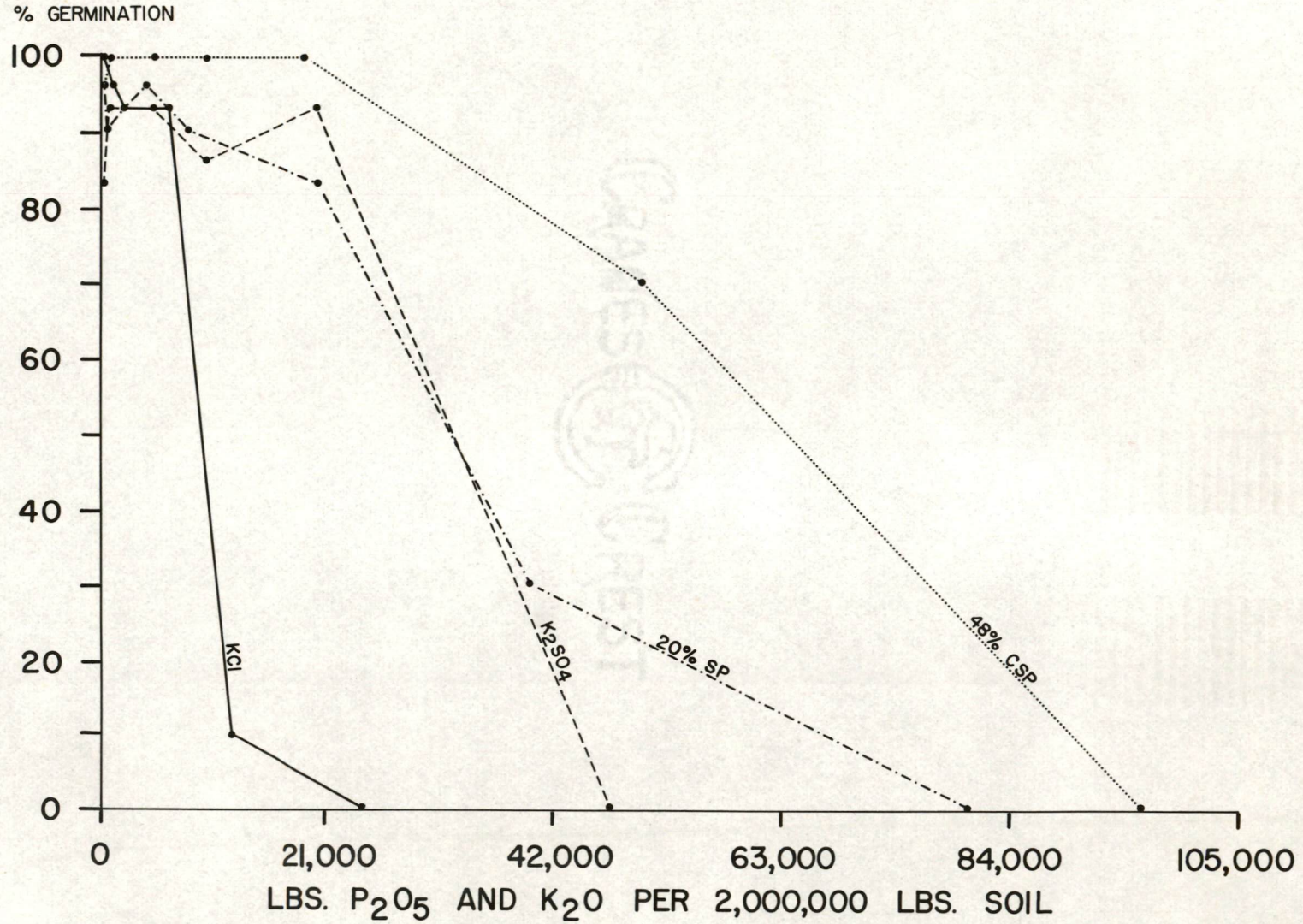


Fig. 7.—Percent germination of corn at 68° F. in a Huntington soil at different concentrations of certain phosphate and potash fertilizers.

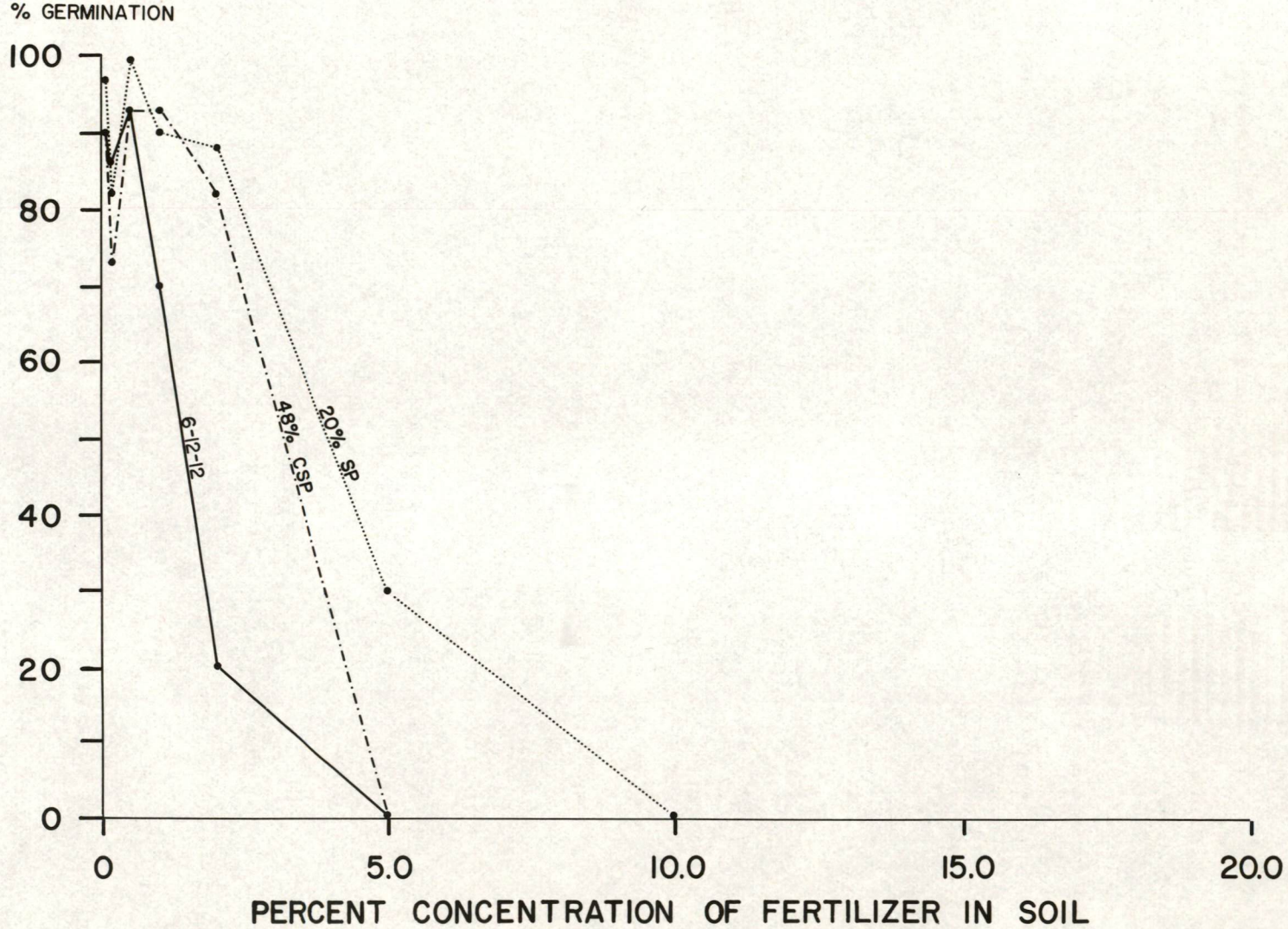


Fig. 8.—Percent germination of wheat at 50° F. in a Huntington soil at different concentrations of two phosphate fertilizers.

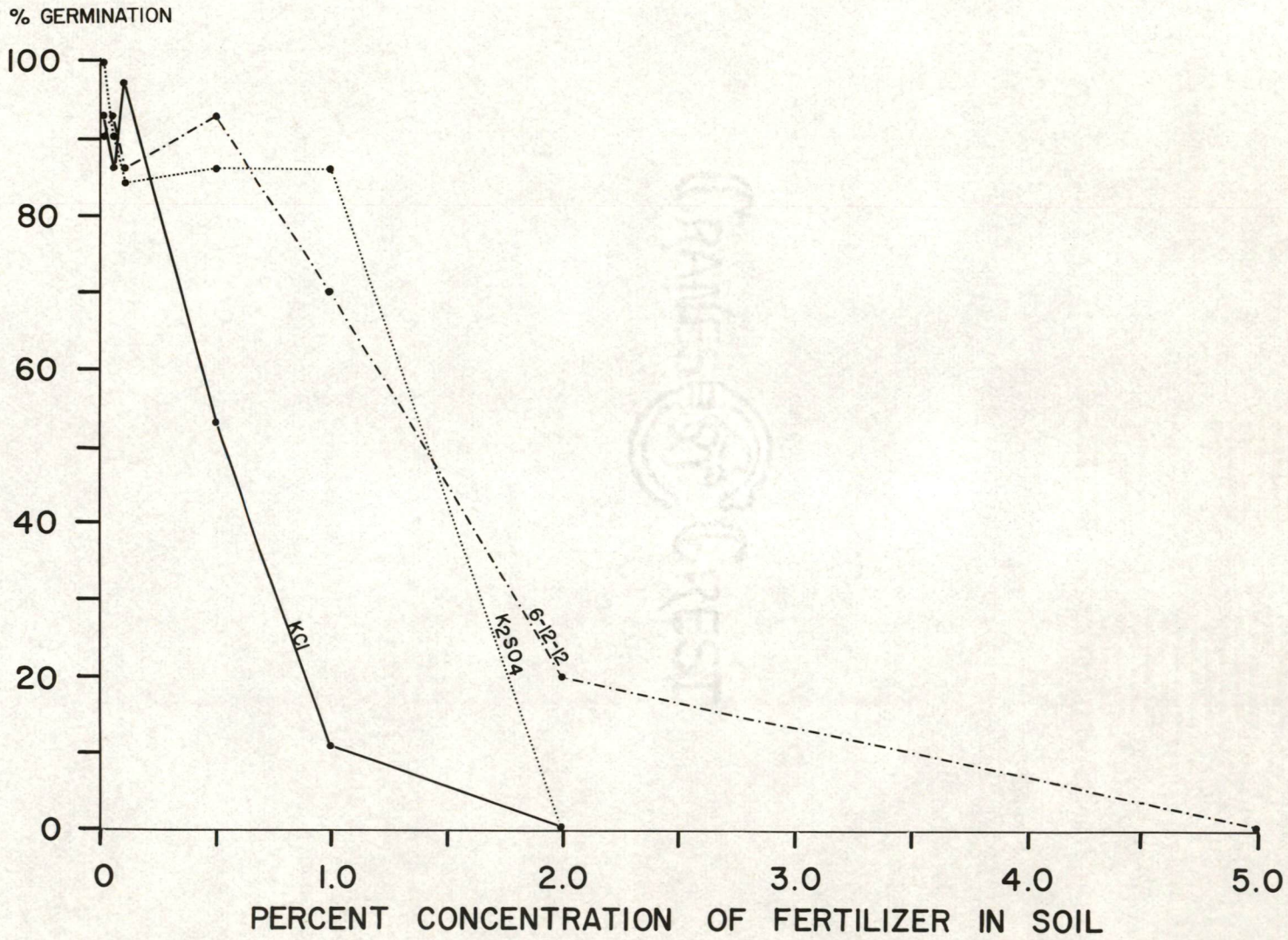


Fig. 9.—Percent germination of wheat at 50° F. in a Huntington soil at different concentrations of two potash fertilizers.

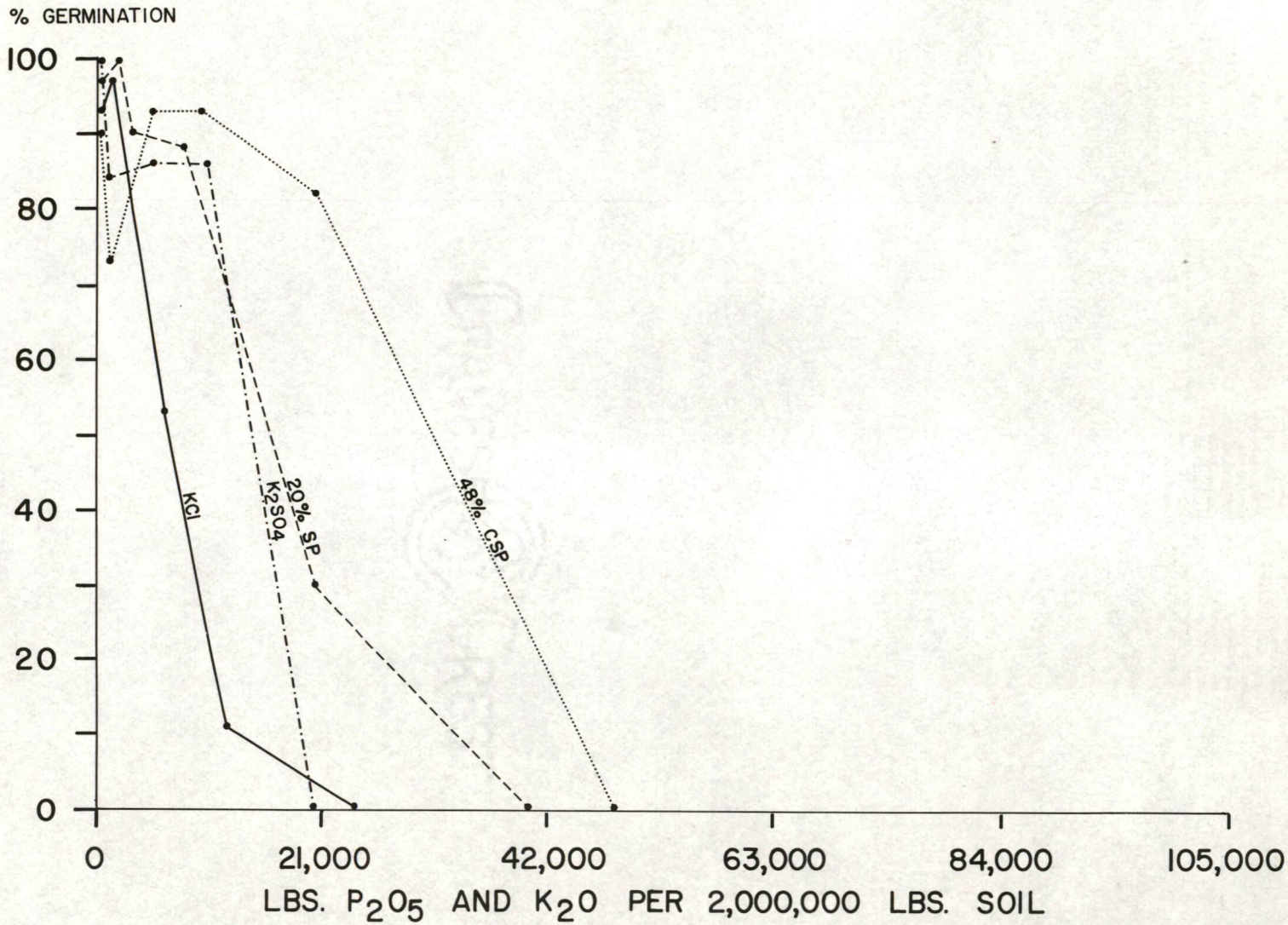


Fig. 10.—Percent germination of wheat at 50° F. in a Huntington soil at different concentrations of certain phosphate and potash fertilizers.

TABLE I

THE PER CENT CONCENTRATION AND POUNDS PER ACRE RATES OF CERTAIN FERTILIZERS AT WHICH DETRIMENTAL EFFECTS TO GERMINATION OF CORN AND WHEAT OCCURRED GROWN IN THE FIELD AND IN GROWTH CHAMBERS

Source	Growth Chambers				Field
	Thoroughly Mixed Per Cent Conc.		Row Application Lbs. N, P_2O_5, K_2O, or Fert. Per Acre		Row Application Lbs. N, P_2O_5, K_2O, or Fert. Per Acre
	Corn	Wheat	Corn	Wheat	Corn
Anhydrous Ammonia	0.05	0.05	—	—	—
Urea	0.05	0.05	15	90	Prills 15 Crystals 30
Nitrate of Soda	0.5	0.5	25	150	30
Ammonium Nitrate	1.0	0.5	50	300	45
Ammonium Sulfate	1.0	0.5	50	150	45
Muriate of Potash	0.5	0.1	75	300	No effect at 60
Sulfate of Potash	2.0	1.0	50	300	No effect at 60
Concentrated Superphosphate	2.0	2.0	100	600	No effect at 60
Ordinary Superphosphate	5.0	2.0	200	600	No effect at 60
6-12-12	1.0	1.0	100	1200	300
3-12-12	—	—	—	—	300
10-10-10	—	—	—	—	300

Ammonium nitrate and ammonium sulfate were not detrimental to corn germination at concentrations of 1.0 per cent or to wheat at the 0.5 per cent concentration. A decrease in the germination percentage occurred at these points with increased concentrations being very detrimental to germination.

Wheat germination was not depressed with concentrations of muriate of potash up to 0.1 per cent. Corn germination was normal up to the 0.5 per cent concentration of muriate of potash. The percentage germination decreased rapidly at concentrations above these values.

Sulfate of potash did not depress corn germination at concentrations of 2.0 per cent or wheat at the 1.0 per cent concentration. Increased concentrations were very detrimental to germination of both crops.

No detrimental effects to the germination of corn and wheat were noted with concentrations of 48 per cent concentrated superphosphate up to 2.0 per cent. Higher concentrations were detrimental to germination with no germination of corn and wheat occurring at the 10.0 per cent concentration level.

Corn germination was not depressed with concentrations of 20 per cent superphosphate up to 5.0 per cent. Wheat germinated normally with concentrations of 20 per cent superphosphate up to 2.0 per cent. Concentrations above these levels were detrimental to germination.

The germination of corn and wheat was not depressed with concentrations of 6-12-12 fertilizer up to 1.0 per cent. Concentrations above 1.0 per cent were detrimental to germination.

The Effect of Fertilizers Applied in the Row in Contact With the Seed

The results showing the effects of fertilizers applied in the row in contact with the seed on the germination of corn and wheat are presented in Figures 11 through 14. Table I shows the concentrations of the various fertilizers. Each germination percentage is the average of three replications at 68° F.

Urea was very detrimental to corn germination at the rate of 15 pounds of N per acre, and wheat germination was reduced severely at the 90 pound rate.

Nitrate of soda reduced corn germination at the 25 pounds of N per acre rate, and wheat germination was damaged at the 150 pound rate.

When applied at the rate of 50 pounds of N per acre to corn and 300 pounds of N per acre to wheat, ammonium nitrate was very detrimental to germination. Rates lower than these had little effect on seed germination.

Corn germination was reduced by ammonium sulfate at the 50 pounds of N per acre rate. Ammonium sulfate at the 150 pounds rate was detrimental to wheat germination.

Sulfate of potash was detrimental to corn germination at the 50 pounds of K_2O per acre rate and to wheat at the 300 pound rate.

The germination of corn was greatly reduced by muriate of potash at the 75 pounds of K_2O per acre rate and of wheat at the 300 pound rate.

When applied at the rate of 100 pounds of P_2O_5 per acre to corn and 600 pounds per acre to wheat, 48 per cent concentrated superphosphate was detrimental to seed germination.

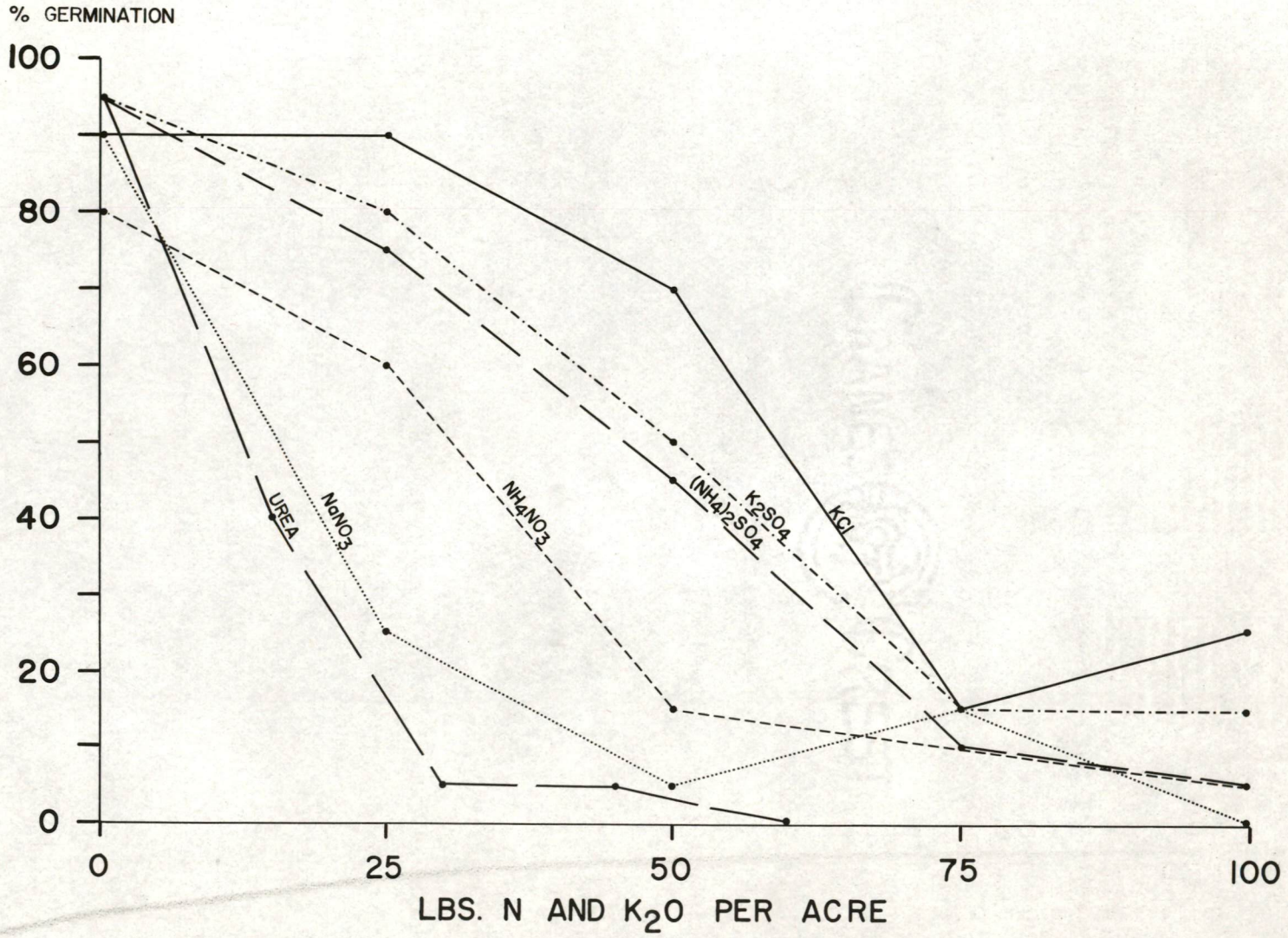


Fig. 11.—Percent germination of corn at 68° F. in a Huntington soil at different concentrations of certain nitrogen and potash fertilizers applied in the row.

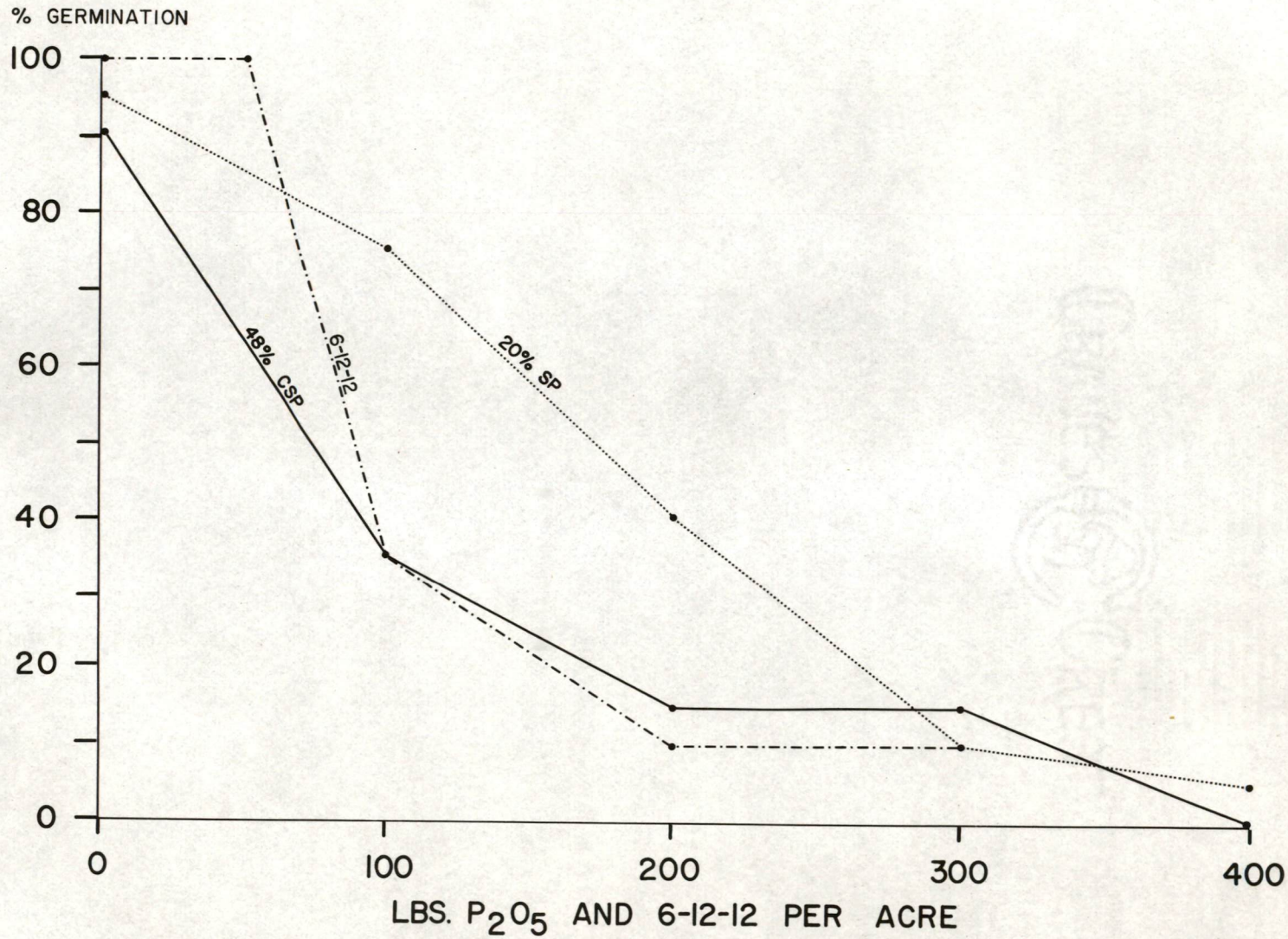


Fig. 12.—Percent germination of corn at 68° F. in a Huntington soil at different concentrations of certain phosphate and complete fertilizers applied in the row.

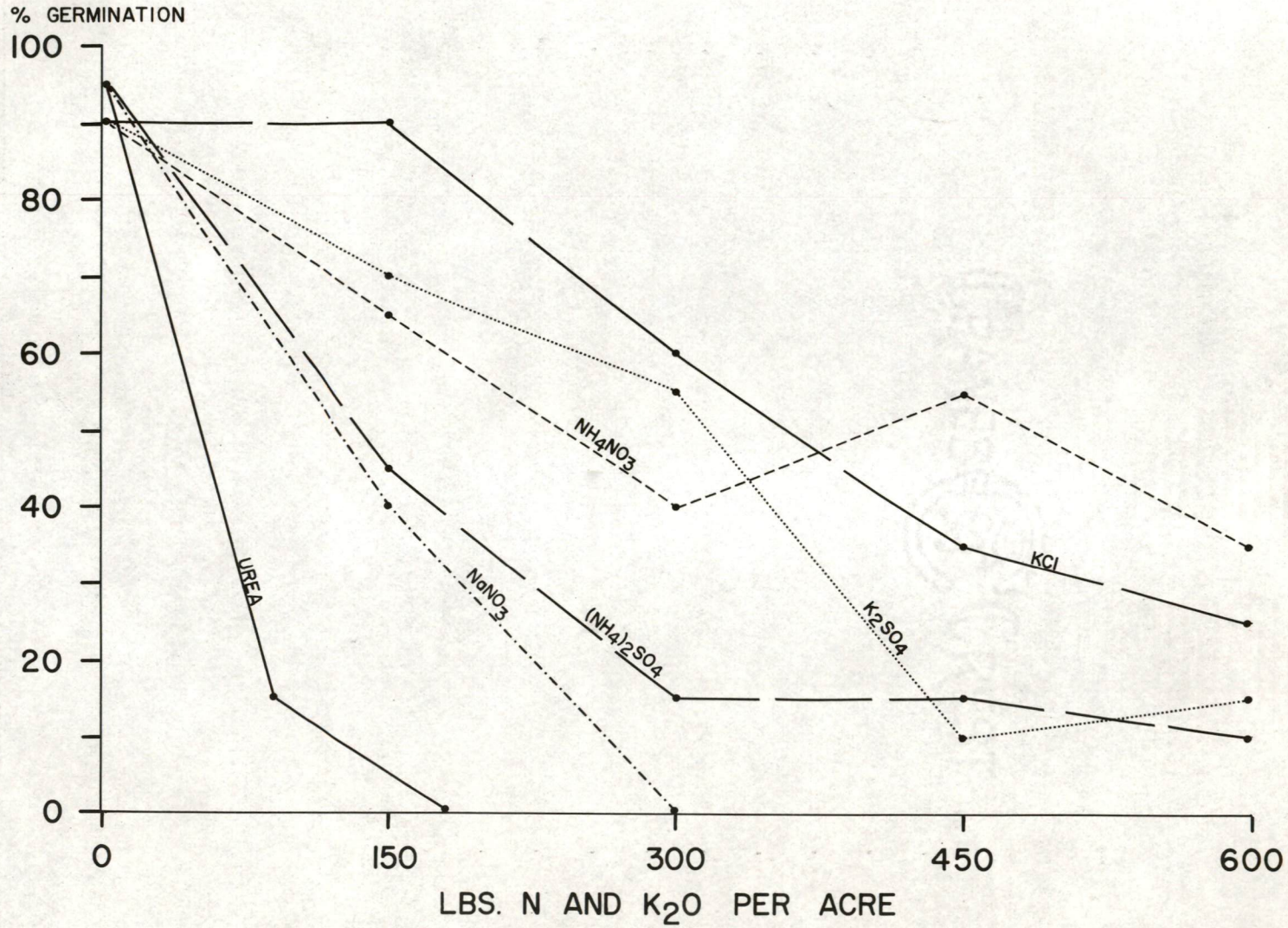


Fig. 13.—Percent germination of wheat at 50° F. in a Huntington soil at different concentrations of certain nitrogen and potash fertilizers applied in the row.

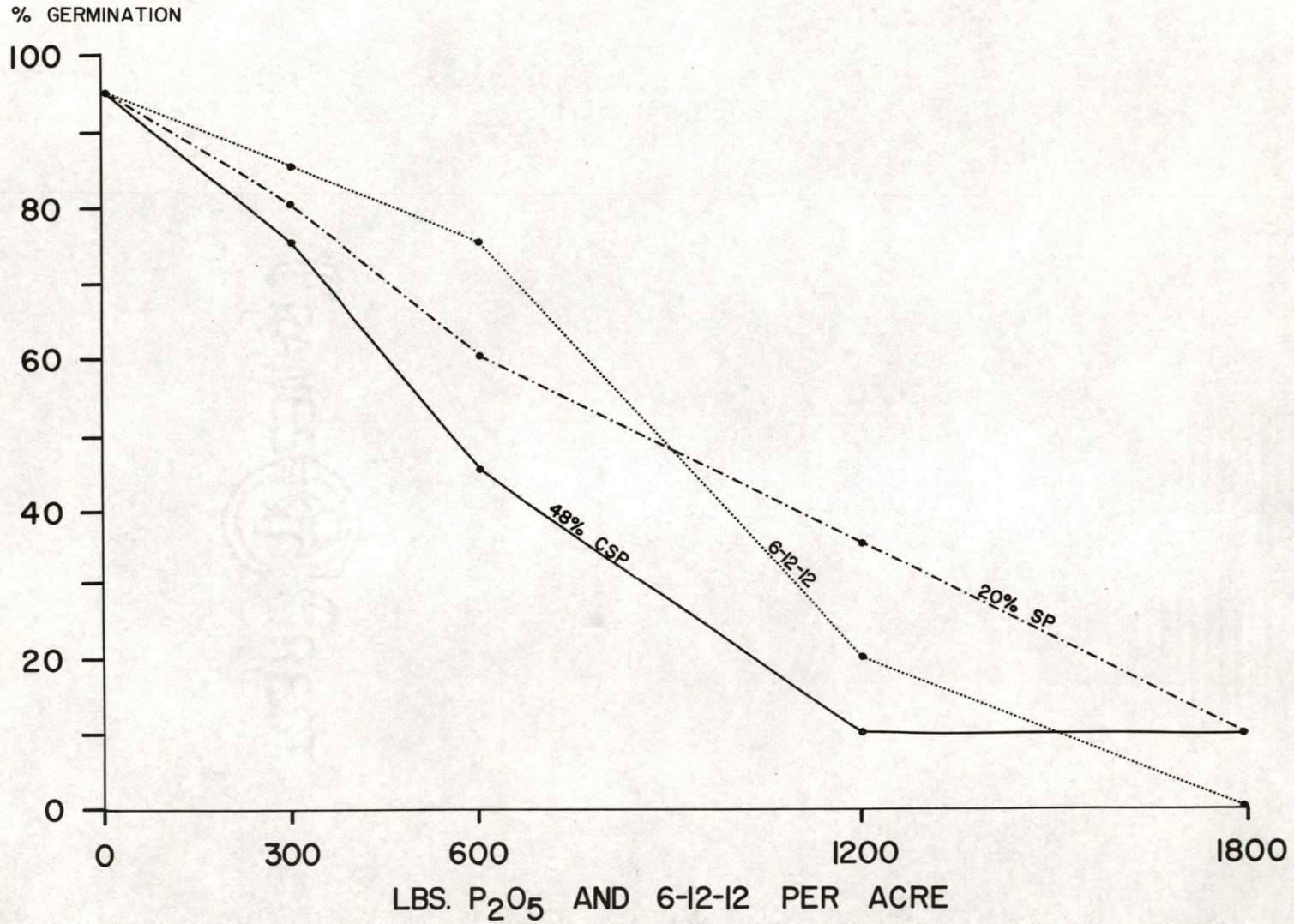


Fig. 14.—Percent germination of wheat at 50° F. in a Huntington soil at different concentrations of certain phosphate and complete fertilizers applied in the row.

Reduction in corn germination occurred with 20 per cent superphosphate applied at the 200 pounds of P_2O_5 per acre rate. Wheat germination was reduced by 20 per cent superphosphate at the 600 pounds P_2O_5 per acre rate.

Corn germination was reduced with 100 pounds of 6-12-12 per acre. Little reduction in wheat germination occurred until the 1200 pound per acre rate of 6-12-12 was reached.

The Effects of Temperature on the Germination of Seed at Various Fertilizer Concentrations

The results of the effects of different temperatures on the germination of seed at various fertilizer concentrations are shown in Appendixes A through J. Corn did not germinate at the 50° F. temperature.

Corn germinated equally well at 68° F. and 86° F. with anhydrous ammonia, ammonium sulfate, and muriate of potash. Germination continued at higher concentrations of urea, ammonium nitrate and sulfate of potash at 68° F. than at 86° F. With increasing rates of nitrate of soda, 48 per cent concentrated superphosphate, 20 per cent superphosphate, and 6-12-12 fertilizer, 86° F. was more favorable to corn germination than 68° F.

Wheat germinated equally well at 50° F., 68° F., and 86° F. with increasing concentrations of anhydrous ammonia, nitrate of soda, and ammonium sulfate. With increasing concentrations of urea, ammonium nitrate, muriate of potash, sulfate of potash, 48 per cent concentrated superphosphate, 20 per cent superphosphate, and 6-12-12 fertilizer, 68° F. was more favorable to wheat germination than 50° F. and 86° F.

The Effects of Fertilizer Salts on Corn Germination Under Field Conditions

Table I shows the concentrations of the various fertilizers at which corn germination was decreased under field conditions.

The complete results of this test are given in Appendix M. Each germination percentage reported is the average of three replications. The no-treatment germination values are the average of twelve plots.

Urea prills were very detrimental to corn germination. Severe reduction in stand occurred at the rate of 15 pounds of N per acre.

Urea crystals and nitrate of soda had little effect on corn germination until the 30 pounds of N per acre rate was reached. Moderate damage to germination occurred at the 30 pounds of N per acre rate with severe damage occurring at the 45 pound per acre rate.

Ammonium nitrate and ammonium sulfate caused a moderate reduction in the stand of corn at the 45 pounds of N per acre rate. Severe reduction in stand occurred at the 60 pounds per acre rate.

In this experiment muriate of potash, sulfate of potash, 48 per cent concentrated superphosphate, and 20 per cent superphosphate had little effect on corn germination. No deleterious effects on germination were noted at the 60 pound per acre rate of P_2O_5 or K_2O.

No reduction of the stand of corn was noted at rates of 3-12-12, 6-12-12, and 10-10-10 up to 200 pounds per acre. Severe reduction in the germination percentage occurred at the 300 pound per acre rate.

CHAPTER V

DISCUSSION AND CONCLUSIONS

It is noted from this study that the fertilizers studied differed in the concentrations at which detrimental effects to germination occurred and also that different species of plants differed in their tolerance to increased salt concentration. The nitrogen and potash fertilizers studied were detrimental to germination at lower concentrations than the phosphate fertilizers. Corn was more tolerant to salt concentrations than was wheat.

The results of this study show anhydrous ammonia and urea to be injurious to germination of corn and wheat at low concentrations of material. Ammonia is very injurious to germinating seed and seedlings. Ammonia is released during the hydrolysis of urea. The high reduction in germination from anhydrous ammonia and urea is probably due to the ammonium ion. Noticeable quantities of ammonia were given off from the urea during the tests in the growth chambers. Tolman and Stout (20) and Salter (13) reported ammonia to be injurious to germinating seed.

The other nitrogen fertilizers studied were less detrimental to germination than anhydrous ammonia and urea. Nitrate of soda depressed germination more than did ammonium nitrate and ammonium sulfate. Similar results were reported by Olson and Dreier (9). These results are contrary to the work of Smika and Smith (17) who stated that ammonium nitrate was more detrimental to germination than urea, and Jackson's (7) work which showed that ammonium nitrate is more depressing than nitrate of soda. The accompanying ion may be an important factor in determining the concentrations

at which detrimental effects occur. Sodium ions are more highly hydrated than ammonium ions; therefore the sodium ions would compete for water more than the ammonium ions. This could affect the rate of water entry into the seed and may account for nitrate of soda being injurious to seed germination at lower concentrations than ammonium nitrate and ammonium sulfate.

The potash fertilizers were comparable to the nitrogen fertilizers in their effect on seed germination. Muriate of potash was more detrimental to germination than sulfate of potash, probably because of the accompanying ions, chloride and sulfate. Salter (13) and Harris (6) reported that the chloride ion was detrimental to germination at lower concentrations than the sulfate ion.

Germination of corn and wheat occurred at higher concentrations of the phosphate fertilizers than the nitrogen and potash fertilizers. Similar results were reported by Coe (3) and Musgrave and Coe (8). The 48 per cent concentrated superphosphate was more detrimental to germination than 20 per cent superphosphate per unit of material. Guttay (5) reported that the injury to germination by phosphate fertilizer is probably due to the free phosphoric acid content. The 48 per cent concentrated superphosphate is more detrimental to germination than 20 per cent superphosphate per unit of fertilizer, probably because of a higher phosphoric acid content.

The effect of 6-12-12 fertilizer on germination was probably due to additive effects of its components. As several ingredients make up a complete fertilizer, one material could not be singled out as the cause of salt injury.

Corn and wheat differed in their tolerance to salt concentration. With the exception of muriate of potash, the fertilizers ranked in the same order in their injurious effects on corn and wheat germination. The main difference was that wheat was less tolerant to salt concentration than corn. Muriate of potash was much more detrimental to wheat germination than to corn germination. Wheat was probably less tolerant to the chloride ion than was corn.

Similar results were obtained from row application of fertilizers in the field and in the growth chambers. The germination percentages of corn dropped at much the same rates with the nitrogen fertilizers in both cases. No comparisons in the potash and phosphate fertilizers can be made because the rates in the field were not high enough to reduce germination. The corn germinated at much higher rates of complete fertilizer in the field than in the controlled tests. This was probably due to a difference in planting procedures. The seed was placed in direct contact with the fertilizer band in the growth chamber, whereas the drill used in the field may not have dropped the corn in as close contact with the fertilizer band.

Figures 1, 3, 5, 6, 8, and 9 show the germination percentages plotted on the basis of per cent concentration. Figures 2, 4, 7, and 10 are based on the pounds of N, P_2O_5, and K_2O per 2,000,000 pounds of soil. The curves break in the same order for the various fertilizers plotted by both bases, except for the phosphate fertilizers. The curve for 48 per cent superphosphate drops before that of 20 per cent superphosphate on the per cent concentration basis. The order is reversed when plotted on the pounds P_2O_5 per acre basis. This is because a higher level of P_2O_5 can be

applied with the more concentrated material and have less concentration of the material in the soil.

Table I shows the rates and concentrations at which the various fertilizers were detrimental to germination. A comparison of the per cent concentrations at which detrimental effects occurred showed more widespread difference among the various fertilizers as to the per unit concentrations at which detrimental effects occur than does a comparison of the materials applied in the row. This difference is probably due to a difference in the salt concentration of the soil solution in the vicinity of the seed with the two means of fertilizer application. An even distribution of the salts throughout the soil solution would be expected in the per unit concentration study, because of the thorough mixing of the fertilizer and soil. The concentration of the salts in solution surrounding the fertilizer band would be dependent on the rate of diffusion of the salt from the fertilizer band into the surrounding soil solution. The rate of diffusion may be dependent on such factors as soil compaction, soil moisture, permeability of the soil, organic matter, nature of the soil colloids, the fertilizer salts involved, and the salt concentration of the soil solution at the time of fertilizer application. This could account for the greater differences among the per unit concentrations of the various fertilizers at which injury occurs than there is among the rates of materials in the row at which injury occurs.

Varying the temperature at planting time did not cause any significant difference in per cent germination of corn and wheat at different concentrations of various fertilizers. It might be noted that 50° F. was too cold for corn germination. There was little difference in per cent

germination of corn at the 68° F. and the 86° F. temperatures. Wheat germination did not vary greatly when comparing the 50° F., 68° F., and 86° F. temperatures. However, there seemed to be a slight tendency for the germination percentages of wheat to drop a little less rapidly at the 68° F. temperature than at the 50° F. and 86° F. temperatures. Faster germination of both corn and wheat occurred at warmer temperatures than at cooler temperatures. There was not enough variation in the per cent germination of either corn or wheat at different temperatures to determine if temperature affected the tolerance of the seed to salt concentration.

CHAPTER VI

SUMMARY

Corn and wheat were grown at different concentrations of various fertilizers in the field and in growth chambers. Three temperature levels were maintained in the controlled tests. The effects of the different fertilizers on germination were noted.

The major results were as follows:

1. Corn was more tolerant to salt concentration than wheat.

2. The fertilizers ranked in the following order with decreasing detrimental effects on the germination of corn: anhydrous ammonia, urea, nitrate of soda, muriate of potash, ammonium nitrate, ammonium sulfate, 6-12-12 fertilizer, sulfate of potash, 48 per cent superphosphate, and 20 per cent superphosphate.

3. The fertilizers ranked in the following order with decreasing detrimental effects on the germination of wheat: anhydrous ammonia, urea, muriate of potash, nitrate of soda, ammonium nitrate, ammonium sulfate, sulfate of potash, 6-12-12 fertilizer, 48 per cent superphosphate, and 20 per cent superphosphate.

4. The nitrogen and potash fertilizers were more detrimental to germination than the phosphate fertilizers.

5. The temperatures studied had no significant effect on the tolerance of corn and wheat to salt concentrations, with the exception that corn did not germinate at 50° F.

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LITERATURE CITED

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APPENDIX

APPENDIX A

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF ANHYDROUS AMMONIA

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.0000	0	90	96	84	90	90
0.0012	0	86	93	84	97	97
0.0025	0	86	96	93	93	93
0.0037	0	93	100	86	97	93
0.0050	0	93	76	82	95	100
0.010	0	83	93	82	88	88
0.025	0	93	96	97	97	93
0.05	0	80	86	80	88	82
0.10	0	0	0	0	0	0
0.15	0	0	0	0	0	0
0.25	0	0	0	0	0	0
0.50	0	0	0	0	0	0

APPENDIX B

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF UREA

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	96	93	82	78	82
0.01	0	100	63	70	91	84
0.05	0	100	40	82	84	77
0.1	0	60	67	42	90	62
0.5	0	0	0	9	49	15
1.0	0	0	0	0	0	0
2.0	0	0	0	0	0	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX C

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF SODIUM NITRATE

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	100	96	93	90	93
0.01	0	100	96	95	95	93
0.05	0	100	90	95	93	100
0.1	0	90	100	95	97	90
0.5	0	100	93	84	90	86
1.0	0	46	96	0	33	17
2.0	0	0	0	0	0	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX D

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF AMMONIUM NITRATE

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	100	96	86	93	97
0.01	0	100	100	93	93	90
0.05	0	100	100	80	86	88
0.1	0	100	96	97	93	97
0.5	0	100	93	84	93	82
1.0	0	93	20	22	80	1
2.0	0	46	0	0	0	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX E

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF AMMONIUM SULFATE

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	90	80	86	90	93
0.01	0	90	86	84	95	75
0.05	0	90	80	88	93	84
0.1	0	76	83	80	90	88
0.5	0	86	83	75	86	64
1.0	0	83	83	37	62	31
2.0	0	0	60	0	0	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX F

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF MURIATE OF POTASH

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	100	100	93	95	93
0.01	0	96	96	95	93	97
0.05	0	96	100	86	100	93
0.1	0	93	93	97	88	97
0.5	0	93	100	53	85	0
1.0	0	10	46	11	57	0
2.0	0	0	13	0	0	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX G

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF SULFATE OF POTASH

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	83	96	100	93	93
0.01	0	86	100	90	95	93
0.05	0	93	100	90	95	93
0.1	0	93	90	84	86	75
0.5	0	93	90	86	88	80
1.0	0	86	96	86	86	27
2.0	0	93	60	0	55	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX H

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF 48 PER CENT CONCENTRATED SUPERPHOSPHATE

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	96	96	90	95	93
0.01	0	96	96	86	95	97
0.05	0	100	86	44	93	86
0.1	0	100	100	73	97	90
0.5	0	100	100	03	93	93
1.0	0	100	96	93	97	84
2.0	0	100	100	82	86	51
5.0	0	70	60	0	0	1
10.0	0	0	70	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX I

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF 20 PER CENT SUPERPHOSPHATE

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	96	90	97	95	95
0.01	0	90	86	84	95	97
0.05	0	90	96	97	95	97
0.1	0	90	96	82	90	95
0.5	0	93	93	100	86	95
1.0	0	96	96	90	97	88
2.0	0	90	100	88	95	84
5.0	0	83	90	30	73	50
10.0	0	30	73	0	0	0
20.0	0	0	40	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX J

PER CENT GERMINATION OF CORN AND WHEAT AT DIFFERENT TEMPERATURES IN A HUNTINGTON SOIL AT DIFFERENT CONCENTRATIONS OF 6-12-12 COMPLETE FERTILIZER

Per Cent Conc. of Fert.	Per Cent Germination					
	Corn			Wheat		
	50°	68°	86°	50°	68°	86°
0.00	0	100	90	90	100	88
0.01	0	96	100	80	90	84
0.05	0	100	93	93	97	88
0.1	0	96	96	86	97	97
0.5	0	100	96	93	97	88
1.0	0	100	93	70	93	80
2.0	0	46	93	20	62	1
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
20.0	0	0	0	0	0	0
30.0	0	0	0	0	0	0
50.0	0	0	0	0	0	0

APPENDIX K

PER CENT CORN GERMINATION AT 68°F IN A HUNTINGTON SOIL AT DIFFERENT RATES OF SEVERAL FERTILIZERS

Source	Pounds N Per Acre				
	0	15	30	45	60
Urea	95	40	5	5	0
	Pounds N or K_2O Per Acre				
	0	25	50	75	100
Nitrate of Soda	90	25	5	15	0
Ammonium Nitrate	80	60	15	10	5
Ammonium Sulfate	95	75	45	10	5
Muriate of Potash	90	90	70	15	25
Sulfate of Potash	95	80	50	15	15
	Pounds P_2O_5 Per Acre				
	0	100	200	300	400
Concentrated Superphosphate	90	35	15	15	0
Ordinary Superphosphate	95	75	40	10	5
	Pounds Fertilizer Per Acre				
	0	50	100	200	300
6-12-12	100	100	35	10	10

APPENDIX L

PER CENT WHEAT GERMINATION AT 68°F IN A HUNTINGTON SOIL AT DIFFERENT RATES OF ROW APPLICATION OF SEVERAL FERTILIZERS

Source	Pounds N Per Acre				
	0	90	180	270	360
Urea	95	15	0	0	0
	Pounds N or K_2O Per Acre				
	0	150	300	450	600
Nitrate of Soda	95	40	0	0	0
Ammonium Nitrate	90	65	40	55	35
Ammonium Sulfate	95	45	15	15	10
Muriate of Potash	90	90	60	35	25
Sulfate of Potash	90	70	55	10	15
	Pounds P_2O_5 Per Acre				
	0	300	600	1200	1800
Concentrated Superphosphate	95	75	45	10	10
Ordinary Superphosphate	95	80	60	35	10
	Pounds Fertilizer Per Acre				
	0	300	600	1200	1800
6-12-12	95	85	65	20	0

APPENDIX M

PER CENT CORN GERMINATION UNDER FIELD CONDITIONS IN A SEQUATCHIE SOIL AT DIFFERENT RATES OF ROW APPLICATION OF SEVERAL FERTILIZERS

Source	Pounds N, P_2O_5, or K_2O Per Acre				
	0	15	30	45	60
Urea Prills	51	16	5	2	5
Urea Crystals	51	40	23	9	5
Ammonium Nitrate	51	42	51	35	19
Nitrate of Soda	51	42	26	9	9
Ammonium Sulfate	51	47	53	33	19
Muriate of Potash	51	77	70	51	40
Sulfate of Potash	51	77	70	63	51
Concentrated Superphosphate	51	79	79	67	53
Ordinary Superphosphate	51	79	72	48	51
	Pounds Fertilizer Per Acre				
	0	100	200	300	400
3-12-12	51	60	56	30	30
6-12-12	51	70	53	28	23
10-10-10	51	58	51	26	16