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Title: THE EFFECT OF DIRECT APPLICATION OF LIQUID FERTILIZERS ON THE GERMINATION, EMERGENCE, AND SEEDLING GROWTH OF WHEAT (*Triticum aestivum* L.)

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The effect of four basic liquid fertilizers: Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution; and one commercial liquid fertilizer, Feast 9-18-9, on germination, emergence, and seedling growth of wheat (*Triticum aestivum* L.) were evaluated under laboratory, greenhouse, and field conditions. Experiments included: 1) preliminary study of basic fertilizer sources to select the ranges of treatments to study in germination, greenhouse, and field experiments; 2) germination experiments on all fertilizer sources to evaluate the effect of selected rates on germination, germination rate index, and seedling dry weight at 10 days after planting; 3) greenhouse experiments on all fertilizer sources to evaluate seedling emergence, emergence rate index, and seedling dry weight at 10 and 20 days after planting; and 4) measurement of seedling emergence, emergence rate index, and seedling dry weight at 10 and 20 days after first emergence, on Woodburn soil at two planting dates to obtain different field environmental conditions.

Preliminary experiments showed three distinct concentration

levels for each source: 1) lethal dose, where no signs of germination were present; were found at 4, 5, 5, and 15 % solution concentration for Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, respectively; 2) critical dose, where concentration levels showed a delay or detrimental effects on germination, was identified at 0.25, 0.08, 0.08, and 3 % solution concentration for the same materials; and 3) safe dose, where seeds produced normal seedlings.

Simple regression analysis on preliminary experiments indicated that as the rate of liquid fertilizer source increased, total germination decreased in a linear manner. For each 10 L ha^{-1} of product applied, germination decreased in 1.52, 0.86, 0.89, and 0.40 % for Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, respectively.

The technique developed in this study appears to be a quick and efficient method to screen for liquid fertilizer toxicity. The laboratory and greenhouse technique allows for more controlled conditions than in field studies. Under field conditions, a greater range of treatments would be required.

Among the basic liquid fertilizers, Thio-Sul showed greater toxicity, on a L ha^{-1} basis, to germinating wheat seeds in germination and greenhouse experiments. Solution 32 and 10-34-0-.9 sources showed a similar and intermediate response in toxicity. Potash solution was tolerated at a much higher concentration. The differences were not detected under the prevailing field conditions.

The commercial liquid fertilizer studied, Feast (9-18-9), showed no detrimental effect at the recommended rates for wheat.

THE EFFECT OF DIRECT APPLICATION OF LIQUID FERTILIZERS ON THE GERMINATION, EMERGENCE, AND SEEDLING GROWTH OF WHEAT (*Triticum aestivum* L.)

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INTRODUCTION

The use of liquid fertilizers and fertilizer solutions has increased dramatically in the U.S. in recent years. Some of the advantages prompting this change are: ease of transport and handling, quick absorption, consistentcy of solution (every drop is the same), even distribution when applied with proper equipment, and the ability to apply different fertilizer nutrients, and pesticides in mixes with the liquid fertilizer materials as carrier.

Sources, rates, and placement of the fertilizer, in combination with soils and climatic conditions, may affect in different intensities the germination, emergence, growth, and yield of crops. In the early years of this century, fertilizer was banded with the seed in the U.S., but as fertilizer rates increased, and as poor germination became a problem, the band application was moved to the side and below the seed.

Many studies have shown the effect of fertilizers applied with the seed, but most were with dry materials. Only a few studies were related to the toxicity levels of liquid fertilizers on early growth of small grains. Most of the research on liquid fertilizers has been conducted on corn, where, at a given rate of fertilizer per hectare, the salt concentration with the seed of corn planted at a 100 cm row spacing is more than five times that with small grains planted at 17.5 cm spacing. Thus, toxic rates found affecting corn germination may be much lower than in small grains. Since the main advantage of applying fertilizer with the seed is to advance early growth, any delay in emergence is likely to cancel the beneficial effect. For this reason the rates of liquid fertilizers need to be carefully controlled.

The primary objective of this research is to determine the level of concentration at which some selected liquid fertilizers affect the germination, emergence rate index, and seedling dry weight of wheat when applied with the seed.

LITERATURE REVIEW

GERMINATION, EMERGENCE, EMERGENCE RATE INDEX (ERI), SEEDLING GROWTH, AND STAND ESTABLISHMENT

GERMINATION: Germination of the seed of the higher plant may be regarded as that consecutive number of steps which causes a quiescent seed, with a low water content, to show a rise in its general metabolic activity and to initiate the formation of a seedling from the embryo (Mayer and Poljakoff-Mayber, 1975). In a seed laboratory situation, germination is defined as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions (Assoc. of Off. Seed Analysts, 1965). From an agronomic view, germination begins when the seed is placed on a moist soil and ends when the seedling emerges above the soil surface and become autotrophic (Cardwell, 1984).

Hadas (1969), defines the term seed germination as a complex array of successive processes which lead to the radicle emergence. Seeds will not germinate unless they are placed under favorable environmental conditions. Among these conditions, he named an adequate water and oxygen supply, a favorable temperature, and a favorable light condition.

Hadas and Russo (1974), indicate that germination of seeds consists of at least three stages: 1) imbibition, during which water sorption is governed by the seed's endosperm or cotyledons content and is the same for viable and non-viable seed; 2) development, or phase during which enzymatic transformation and initiation of meristematic activities take place; and 3) growth, which begins with radicle elongation and emergence through the seed coat.

EMERGENCE: Emergence is defined as the appearance of the first leaves above the ground. Depending on the growth activity of the hypocotyl, dicotiledonous plants emerge in two different ways: 1) epigeal emergence (more than 90 % of the species), the hypocotyl is active and pulls the cotyledons above ground during its growth, and 2) hypogeal emergence were the hypocotyl remains inactive and the cotyledons remain below ground. All grasses have hypogeal emergence as the hypocotyl is inactive and the scutellum remains below ground. Emergence of most grasses is largely dependent on elongation of the coleoptile and the first node (Nelson and Larson, 1984).

EMERGENCE RATE INDEX (ERI): ERI is the ability of seeds to germinate and emerge rapidly under different climatic conditions. Rate of emergence is an important characteristic for plant establishment. The speed of seedling emergence in cereals is influenced by environmental factors such as soil temperature, soil moisture, and physical properties of the soil (Ahmad, 1987).

SEEDLING GROWTH: Seedling growth covers the period in the life cycle of green plants from emergence of the radicle through the seed coat until the appearance of enough green leaves to make the plant independent of stored energy. The major activity of seedling growth is the establishment of roots and shoot tissue for autothrophism (Nelson and Larson, 1984).

STAND ESTABLISHMENT: A crop stand is established when the seedling plants have developed to a stage when the potential yield of a given crop can be expressed at the final harvest (Bolton, 1987). Among principal components of stand establishment are time or date of establishment, seeding density, planting pattern, and seed quality. From a farmers point of view, early seedling establishment in the Fall is attractive because they obtain good vegetative cover to intercept light and minimize soil loses from wind and water erosion.

Establishment of small grains crops is particularly delicate especially under dry land conditions. Although there may be adequate subsoil moisture, the soil surface is frequently dry to a depth of 2.5 cm or more at seeding time. Likelihood of successful establishment is enhanced if the seed can be placed in moist, warm soil.

FACTORS AFFECTING GERMINATION, EMERGENCE, ERI, SEEDLING GROWTH, AND STAND ESTABLISHMENT

Proper seed germination, emergence, and good stand establishment are necessary for economic grain yield. Seed germination and subsequent seedling emergence can be influenced by planting depth (Lindstrom et al., 1976) soil temperature (Tadmor et al., 1969), soil strength (Parker and Taylor, 1965), soil bulk density (Hanks and Thorp, 1956), salinity (Ayers, 1952), varietal differences (Helmerick and Pfeiffer, 1954), and in particular soil water potential (Hadas, 1969). Dubetz et al., (1962), indicate that germination of viable seeds is perhaps more dependent on soil temperature and soil moisture than on any other factor.

EFFECT OF SOIL MOISTURE

Before a seed can germinate, a hydration process must occur. Water must be absorbed into the endosperm and embryo through the seed coat.

The initial step in germination is the imbibition (uptake) of water by the various tissues of the seed. This process is a function of water availability, either in the liquid or gaseous form, seed chemical composition, and the seed cover permeability (Mayer and Poljakoff-Mayber, 1975).

The germination process starts just after water content of the seed reaches a critical level if the other factors are optimum for germination. The minimal amount of water which must be present for germination varies depending on species. For example, in maize, rice, soybean, and wheat 31, 25, 50, and 40 percent moisture, respectively, must be present on a weight basis (Brown, 1965). The germination process is complete with the emergence of the radicle from the embryo.

Hunter and Erickson (1952) reported that in order to germinate, corn, rice, soybean, and sugar beet seeds have to attain a specific moisture content. This minimum moisture content was approximately 30.5, 26.5, 50.0, and 31.0 percent, respectively. Seeds of the same crops would not imbibe enough water for germination when the moisture stress was below 12.5, 7.9, 6.6, and 3.3 atmospheres of osmotic pressure, respectively.

Doneen and MacGillworay (1943), measured the effects of soil moisture on 22 species of garden vegetables and reported that seedling emergence was retarded and reduced as moisture stress increased. They also observed that the germination percentage for some crops is lowered as the soil moisture decreased toward the wilting coefficient, but for some crops the proportion of seeds germinated is not influenced as long as the soil moisture is above the wilting coefficient. However, seeds of all crops germinated in a shorter time with higher soil moisture than with lower.

Helmrich and Pfeiffer (1954), used mannitol solutions to obtain moisture stress with winter wheat and reported that, as moisture stress increased, germination was delayed and reduced and the rate of seedling growth was reduced. Gul and Allan (1976), found that total stand, coleoptile length, seedling height and root weight of wheat were progressively reduced as water potential decreased.

EFFECT OF TEMPERATURE

Slow germination and low seedling vigor limit emergence and early stand establishment of crops, and temperature is a major environmental factor influencing those processes.

Minimum, optimum, and maximum temperatures for effective germination vary with other environmental conditions, as well as with different varieties and age of the seed. Each plant has a minimum and a maximum temperature at which no seeds will germinate, and an optimum temperature at which germination will be greater. In general the cardinal temperature for germination of wheat are approximately: minimum, 3.5-5.5 ^{o}C; optimum, 20-25 ^{o}C; maximum, 35 ^{o}C, although weak germination has been reported to occur at 0 ^{o}C and also at 40 ^{o}C (Peterson 1965). Wilson and Holles (1927) studied the effect of various temperatures on the germination of wheat. They found a temperature of

15 ^{o}C to be nearly optimum for germination of wheat. Soil temperatures above 30 ^{o}C have been reported to adversely affect the germination and seedling emergence of wheat varieties (Burleig, Allen, and Vogel, 1965).

Dubetz, Russell, and Anderson (1962), studied the rate and percentage of emergence of 19 native and cultivated herbaceous species at 6, 12, 18, and 24 ^{o}C soil temperature. The rate of emergence of all species was greater at 18 ^{o}C than at 6 ^{o}C, and for all but five species was greater at 24 ^{o}C than at 18 ^{o}C. The percentage of emergence of barley, bromegrass, crested wheatgrass, mustard, oats, peas, spring wheat, and wild oats was not significantly affected by soil temperature. Alfalfa, creeping red fescue, winter wheat, orchardgrass, rough fescue, sweet clover, and flax emerged best at moderate soil temperatures. Beans, corn, sugar beet, and sunflower showed significantly lower emergence percentage at 6 ^{o}C than at the three higher soil temperatures.

Daily emergence counts were made by DeJong and Best (1979), on Canthach wheat grown in five soil types, at four soil temperatures, with three water potentials, and planted at five different depths. Regardless of soil types, soil water potential, or depth of planting, 50 % emergence generally occurred within a week at 19.4 and 26.7 ^{o}C, and within 2 wk at 12.2 ^{o}C, but it took up to 6 wk at 5 ^{o}C.

Temperature and depth of seeding both have a marked influence on the morphology of the seedling wheat plant (Taylor and Mc Call, 1936). They found that when the seed was sown only 18 mm depth, much larger coleoptiles were produced at 20 ^{o}C and 24 ^{o}C than at 12 ^{o}C and 16 ^{o}C.

Alessi and Power (1971), conducted field and growth room experiments to evaluate the effect of seed depth and soil temperature on corn germination and emergence. In the growth room, from 4 to 24 days were required to achieve 80 % emergence, depending on soil temperature and seed depth. Increasing soil temperature from 13.3 to 26.7 ^{o}C reduced the time for 80 % emergence. Temperature had a much greater effect than seed depth on emergence. In field treatments with adequate soil water for germination, 8 to 13 days were required for near 80 % germination. About one additional day was required for each 2.5 cm increase in depth of planting. Allan et al. (1962), found that low soil temperatures greatly reduce coleoptile length and, subsequently, lessens the ability of seedlings to emerge properly.

Kanemasu, Bark, and Chin Choy (1975), found that soil temperatures strongly influences both percentage germination and time of emergence of sorghum. Results of the study indicate an optimum germination temperature of about 23 ^{o}C and a heat requirement of 67 degree days. At the optimum soil temperature the percentage field emergence was 81 %, about 7 % lower than laboratory germination.

Comparing the effect of alternating temperatures versus constant temperatures, a slower germination was noticed at an alternate temperature cycle of 16 hours at 15 ^{o}C and 8 hours at 25 ^{o}C than at constant temperatures of either 10 ^{o}C or 20 ^{o}C (Ching and Foote, 1961).

EFFECTS OF TEMPERATURE AND MOISTURE INTERACTIONS

The interactions that occur between soil moisture and soil temperature have a great influence on germination and seedling emergence. Tadmor, Cohen, and Harpaz (1969), found that the germination rate of wheat was affected by temperature and water potential, however,the effect of water potential was dependent on temperature. Evans and Stickler (1961) reported similar temperature and water potential effects on germination and seedling emergence. Halitligil (1975) showed that the germination rate is lowered as either the temperature or water potential decrease, but that the effect was greater when both decrease.

McGuines (1960), reports a study of the effect of 6 levels of moisture stress at 3 levels of temperature on the germination of 6 species of grass commonly used in range seeding. Increased moisture stress delayed germination, reduced emergence rate and 28-day total of germination. Highest average germination was at 20 ^{o}C. Under high moisture stress all species germinated better at 20 ^{o}C than at 10 or 30 ^{o}C. Seed size showed positive correlation with germination at a stress of 15 atmospheres.

Morrison et al. (1981), found a highly significant interaction for temperature and moisture tension for the percent emergence and emergence rate of soft red winter wheat. They reported the best combination of 3.9 ^{o}C and 3 atm tension to distinguish cultivars for emergence.

Sharma (1976) studied the interactive effects of temperature with matric and osmotic potential on germination characteristics of three dryland species. He found that the rate and total germination of all the species declined with decreasing water potential. The germination rates increased with increasing temperature but final germination were highest at intermediate temperature (20 to 25 ^{o}C). Interactive effects of temperature with both types of water potentials were highly significant for all species.

EFFECT OF SOIL TEXTURE AND BULK DENSITY

Emergence of many seedlings is greatly influenced by soil physical conditions as compactability, texture or particle size, and its relation with moisture retention. Hanks and Throp (1956) measured wheat seedling emergence as affected by soil moisture and bulk density for three soils varying in texture from silty clay loam to a fine sandy loam. Their data showed that higher bulk densities restricted seedling emergence primarily because of greater soil strength.

Soil compactation generally influences coleoptile length. Kaack and Kristen (1967), found that as soil compactation increases, coleoptile length of winter wheat was reduced. Total emergence and rate of emergence were also decreased.

Laboratory studies were conducted to evaluate effects of soil type, soil moisture tension, temperature, and planting depth on relations between soil strength and seedling emergence of sorghum (Parker and Taylor, 1965). With 4 of 6 soils tested, small amounts of compression apparently increased seedling emergence, but emergence was progressively decreased by increases in soil strength above 3 bars. When strength of Miles soil exceeded 13 bars, no emergence occurred. With the other 5 soils tested, no emergence occurred when soil strength was greater than 18 bars.

EFFECT OF VARIETAL DIFFERENCES

The ability of a wheat variety to germinate and emerge is controlled genetically and is an integrated response to all environmental factors, consequently varieties do respond differently to such factors as soil moisture, temperature, and physical properties of soils.

Germination and early growth of Yogo winter wheat were significatively superior to the germination and early growth of Cheyenne winter wheat when germinated under controlled limited-moisture conditions (Helmrich and Pfeiffer, 1954). Morrison et al. (1981), found significant differences among four soft red winter wheat cultivars for percent emergence and also mean rate emergence under laboratory conditions. Highly significant differences were found in the emergence percent and coleoptile length of 9 winter wheat varieties in both field tests and in the coleoptile length of varieties tested in the laboratory (Sunderman, 1964).

Seeds of 26 wheat varieties, produced at two locations, were compared for several seed characteristics and for field emergence at three locations (Ahamad, 1986). Varieties showed different behavior among the classes and in some cases were different within a class when compared for their emergence rate index. Allan et al (1965) found no significant differences in germination rates among 33 semi-dwarf wheat varieties.

Seedling emergence and the growth of seedlings of 93 wheat lines developed for improved seed vigor, and four check cultivars were studied at four soil water levels. Studies in laboratory and in field revealed that the lines differed markedly in their emergence characteristics. ERI was high for a number of lines in all four soil water potentials. The time required for emergence nearly doubled for each decrease of water potential of -4 bars within the range studied (Gul and Allan, 1976)

Evans and Stickler (1961), found that total germination in 4 varieties of sorghum progressively decreased with increasing moisture tension from 0 to 15 atmospheres. Analysis of variance of the data, expressed as percent of germination of check (0 atm), revealed highly significant differences among varieties, among moisture tensions, and for the interaction of these two variables.

Varieties and selections with long coleoptiles emerged more rapidly than those characterized by shorter coleoptiles. ERI were found to parallel coleoptile length. Standard-height varieties produced longer coleoptiles than semidwarf for 2, 3, and 4 inch depths at 50 ^{o}F. At the 3 and 4 inch planting depths emergence was reduced between 15 and 49 % at 50 ^{o}F and 48 to 81 % at 90 ^{o}F when compared to emergence percent at 2 inch depth (Burleigh, Allan, and Vogel 1965).

Significant differences in ERI were observed by Allan et al. (1962), working with a group of standard height and semidwarf wheat cultivars as well as for groups of club and common semidwarf selections. Indexes were found to correlate positively with mature plant height and coleoptile length of seedlings grown at 50 ^{o}F and 90 ^{o}F. Partial correlation indicated that associations between ERI and plant height and ERI and coleoptile length were closely related.

EFFECT OF SEED AGE

Total emergence and vigor decreased as seed age increased. This was not reflected in germination percentage. Shoot weight of individual seedling was not significatively affected by the seed age (Kittock and Law, 1968).

EFFECT OF PROTEIN CONTENT OF THE SEED

The quality and quantity of food reserves is an important component of seed quality that contributes to plant vigor. The vigor of seedling growth may be described as the relative growth rate during early plant development. Research has demonstrated that within a genotype, high protein seeds will produce more vigorous seedlings and sometimes higher yields. Ries and Everson (1973), worked with five cultivars of spring and winter wheat grown at several different locations to determinate the relative effect of genotype and environment on seed protein and seed size. Those factors were related to the dry weight of seedling shoots (vigor). Both environment and genotype affected the protein content of the seed. Regardless of genotype or environment, seedling vigor was consistently related to seed protein.

Results obtained by Lowe and Ries (1972), under controlled environmental conditions and using equal seed size, showed significant differences in dry matter and a high positive correlation between seed protein content and dry matter up to 40 days from sowing under different temperature and light intensity environments with nutrient concentrations containing up to 24 mM nitrate. Schlesinger (1970, in Lowe and Ries 1972), found that when the seed protein level is increased, either by the use of nitrogen fertilizer or by selection of large seeds for sowing, the seedling vigor of the next generation can be increased. The seedling dry matter content showed a high positive correlation with the seed protein content of 17 phenotypes of a Mexican semidwarf wheat (Lowe, Ayers, and Ries 1972).

Lopez (1972), found a positive relationship between seed protein content and plant performance. High protein seeds had a faster speed of germination and developed into larger seedlings with a higher dry matter content when grown in nitrogen-deficient soil. In nitrogen-enriched soil, seed protein content had little effect on seedling growth.

EFFECT OF SEED SIZE

Seed size has also been shown to influence seedling establishment. Generally large seeds produce more vigorous seedlings. Seed size and planting depth significatively influenced the emergence of wheatgrass (Agropyron spp.) seedings. The larger seeds gave the best emergence at greater depths (Rogler, 1954). The author also suggested than seedling vigor could be increased by selecting for large-seeded types. High positive correlation suggest that ability of intermediate wheatgrass to emerge from deep seedlings is closely related to seed size and coleoptile length (Hunt and Miller, 1965).

Kittock and Law (1968) reported that, in wheat, germination and emergence were positively correlated with seed weight for five seed size classes. Kneebone and Cremer (1955) reported that seedlings from larger seeds of several grass species emerged faster. Lafond and Baker (1986), found that plants grown from small seeds emerged faster but accumulated less shoot dry weight than plants emerging from large seeds. Seed size accounted for approximately 50 % of the variation in seedling shoot dry weight.

Evans and Bhatt (1977) reported that they found a highly significant correlation between seedling vigor (as measured by seedling weight 20 days after planting) and seed size.

The relationship between seed size, establishment, and final yield of barley has been largely investigated by Kaufmann and Guitard (1967), and Kaufmann and McFadden (1960 and 1963). They have shown that plants grown from large seeds are superior to those grown from small seeds, in rate of seedling growth and size of the first two leaves. Boyd, Gordon, and LaCroix (1971), found marked differences in seedling vigor as measured by dry weight two weeks after germination of F3 lines of a barley cross. These differences can be largely accounted by differences in seed size. The researchers conclude that, although seed size, directly and indirectly, can influence seedling vigor, inherent differences in this respect exist between barley cultivars.

Field experiment results with three seed sizes and three seeding rates of three barley varieties indicated that the size of the seed had no effect on emergence as determined by seedling counts (Demirlicakmak et al. 1963).

EFFECT OF PROTEIN CONTENT AND SEED SIZE INTERACTION

In greenhouse and field studies with green beans (Phaseolus vulgaris L.), seed size and protein content were found in the expression of seedling growth and bean yield, but when the effect of seed size was statistically removed, yield was related to protein content (Ries 1971).

In the Ries and Everson (1973) work mentioned earlier, seedling vigor was also related to seed size, but when seed size was eliminated as a factor by using uniformly sized seed, the seed protein content and vigor relationships were significant.

FERTILIZER EFFECTS

Germination of seeds may be delayed and reduced if placed in contact with commercial fertilizers in the soil. Soluble fertilizer salts increase osmotic pressure of the soil solution and may thus retard water uptake by seeds. As soil moisture content is decreased, moisture stress is increased, and the effects of salt in delaying and reducing germination becomes greater. Damage is more prevalent on lighter textured soils because their lower water-holding capacity. Apart from these effects, certain ions contained in fertilizers are toxic to germinating seeds.

Some fertilizers placed in the soil near wheat seeds reduced and delayed germination. The amount of delay and reduction varied with the fertilizers, temperature, moisture, and distance from seed to fertilizer (Read and Beaton, 1963). The extent to which germination is affected when fertilizer comes into contact with the seed depends on the kind and concentration of the fertilizer. The concentration depends on the rate of application, properties of the fertilizer, and soil moisture level (Evans and Stickler, 1961).

Increased moisture tension, whether caused by lower moisture content or by higher osmotic pressure, makes water less available to the seed and may be detrimental to germination. Fertilizers applied near the seed will compete with the seed for moisture by increasing the osmotic potential of the soil solution (Read and Beaton, 1963).

Relatively few studies have been conducted on small grains with liquid fertilizers, as compared with dry fertilizers, to determine the their effects on seed germination, emergence and seedling growth.

DRY FERTILIZERS

Commercial fertilizers have an osmotic effect on germination. Urea and anhydrous ammonia are detrimental at concentrations of 0.0005 to 0.001 mole fraction, and potassium fertilizers cause injury at concentrations of 0.005 to 0.02 mole fraction. Phosphates are the least toxic, with concentrations of 0.05 to 0.1 mole fraction required for injury (Cardwell, 1984).

Investigations in Texas by Collier (1954) showed that most of the yield reduction, caused by fertilizer placed with the seed, was due to retarded emergence, and that the reduced seedling and plant vigor was caused by excessive salt concentration rather that by loses in plant population.

Tolerance of germinating seeds to salt concentration varies among species. Ayers and Hayward (1948) found barley to germinate at the highest levels of salinity for a number of species tested. Nyborg (1961) found the following order of tolerance among the crops studied: oat > barley > wheat > rape > flax.

Chapin and Smith (1960) found little effect of moisture variation on germination of wheat but the rate of germination was reduced with increased rates of fertilizer applications. They also found that ammonium nitrate reduced germination more than potassium chloride.

Nyborg (1961) using ammonium nitrate, ammonium phosphate, and triple superphosphate fertilizers found that nitrogen fertilizer was more injurious than either phosphate fertilizer when applied on the basis of N and P_2O_5 content. Injury to emergence increases with lower soil temperature and with lower soil moisture. Injury to emergence was eliminated when fertilizers were broadcast or placed in a band one inch or more away from the seed.

Olson and Dreier (1956) reported that applications 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 N per acre adjacent to the seed during periods of low soil moisture.

In work done by Coe (1926) 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 % P_2O_5 material in contact with the seed were reached. Nitrate of soda and muriate of potash at rates of 100 pounds per acre in the row completely inhibit germination.

Read and Beaton (1963) in laboratory studies measured the effects of fertilizer, temperature, and moisture. Six fertilizer sources were used and wheat seeds were placed 0.5, 1.5, and 2.8 cm away from the fertilizer. Total germination was reduced by fertilizer source, while moisture level and temperature had little effect. Total germination was reduced more when seed was placed close to the fertilizer. The rate of germination was significatively affected by all factors. Low temperature reduced the speed of germination but to a different extent with different fertilizers. Decreasing soil moisture increased the time required for germination, but here also individual fertilizers reacted differently.

Corn and wheat were germinated with different concentrations of various fertilizers in growth chambers. Three temperature levels were maintained in the controlled test. 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 % superphosphate, and 20 % superphosphate. The temperatures studied had no significant effect on the tolerance of corn and wheat to salt concentrations (Cummings and Park, 1961).

Smika and Smith (1957) studied the effect 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 those at field capacity no appreciable effects were noted until the 80 pound per acre rate was reached.

Severson and Mahler (1988) conducted two studies under greenhouse conditions to determine the effects of banding Sulfur-coated urea (SCU) in direct contact with spring barley at different soil matric potentials. Three SCU materials with varied release rates (SCU-10, SCU-20, and SCU-30) were banded with the barley seed at N rates of 0, 34, 67, 101, and 134 kg ha^{-1}. As single parameters both water potential and nitrogen application rate had significant effect on spring barley emergence.

LIQUID FERTILIZERS

Raun, Sander, and Olson (1986) conducted three experiments in Nebraska to evaluate the effect of rates of salt and solution fertilizer sources on corn emergence. The salt rates used were 0, 5, 10, 15, and 20 lb/ac, and source used were 7-21-7, 7-21-7 with ammonium thiosulfate, 10-34-10, and 9-18-9 of solution fertilizer placed with corn at planting. In two of these experiments small amounts of salt (5 lb/ac N + K_2O) reduced corn seedling emergence nearly 10 % whether or not precipitation occurred soon after planting. Salt rates in excess of 10 lb/ac delayed seedling germination until precipitation occurred, resulting in small corn plants emerging in established corn stands. Fertilizer sources did not significatively affect seedling germination.

Bates (1971) studied the effect of fertilizer banded with the seed of corn at rates supplying 3.1, 5.4, and 2.5 g N, P, and K per meter of row, respectively, in 22 field trials. Fertilizer with the seed delayed and reduced emergence in several trials, but on the average it increased the dry weight of 36-day-old plants in 36 percent.

Miller et al. (1971) in greenhouse trials investigated the effectiveness of small amounts of fertilizers placed directly with the seed of corn. Four rates: 0, 56, 112, and 168 kg ha^{-1} of the 6-10.5-5 fertilizer solution were applied to corn in Huron silty clay loam and Tucsola silt loam soils. In the Huron soil, the 56 kg ha^{-1} rate of fertilizer caused only a slight delay in emergence and did not significatively reduce the final number of plants emerged. The 112 kg ha^{-1} rate delayed emergence appreciably, and the 168 kg ha^{-1} rate delayed emergence even more. Results with the Tucsola silt loam were almost identical to those with the Huron silty clay loam soil. Although the danger of generalizing greenhouse data to field conditions is realized, the authors conclude that an appreciable delay on emergence can occur at rates higher than 56 kg ha^{-1}.

Seedlings of 24 spring barley varieties were grown in sand with continuous light and supplied with a complete nutrient solution, or with a solution lacking nitrogen or phosphorus. Significant differences were found among varieties in necrosis of first leaf blades induced by lack of phosphorus (Jensen and Nittler, 1971)

Boatwright and Viets (1966) using solution cultures to study P absorption during various growth stages of spring wheat and intermediate wheatgrass found that a supply of P for the first 5 wk (up to heading for wheat) was adequate to produce maximum dry matter for both species and for maximum grain production of wheat. Maximum root development was achieved when P was supplied for the first 4 weeks of growth. Spink and

Baker (1947) found that the principal source of P uptake during the first 4 weeks after seeding was the applied fertilizer whereas native soil P provided the principal source later in plant development.

DRY VERSUS LIQUID FERTILIZERS

Baweja and Bates (1971) compared powdered and granular fertilizers containing 13.3, 23.1, and 11 % nitrogen, phosphorus, and potash respectively, prepared along with water solutions of the same material containing 10.5 and 4.4 % phosphorus. These fertilizers were banded with the seed of corn in the greenhouse trials. No differences in nutrient availability were found between liquid and dry fertilizers studied. Granular and powered materials were equal in toxicity. They were more toxic to corn seedling, as measured by axis length, emergence, or dry matter yields, than the less concentrated liquid, providing equal quantity of plant nutrient.

Results of many experiments comparing liquid and solid sources of N carriers have shown that when used properly, equal crop response is obtained with anhydrous ammonia and nitrogen solutions as with same amounts of actual N applied in the solid form (Lathwell et al., 1960)

Miller et al. (1971) compared dry and liquid fertilizers banded in the seed row at a rate supplying 7.3, 6.5, and 6.0 kg of N, P, and K per hectare, respectively; and a third treatment with dry fertilizer banded 3.8 cm to the side and 3.8 cm below the seed at a rate supplying 56.0, 24.6, and 46.5 kg of N, P, and K per hectare respectively. The dry fertilizer with the seed reduced emergence to 25 % of the check (no fertilizer) and, as a result, no further data was obtained. Most of this reduction in emergence is believed to have been due to NO_3- and Clwhich were used only in this material. Neither of the other treatments significatively affected emergence. Plants receiving the liquid fertilizer with the seed grew more rapidly during the first 4 weeks than plants of the check or side band treatments. At 7 weeks the dry matter production was still somewhat greater than that from the side band, although the plant heights were essentially the same.

METHODS AND MATERIALS

Experiments were conducted to determine the effects of different levels of four basic liquid fertilizers: Solution 32, 10-34-0-.9, Thio-Sul, and Potash Solution; and one commercial liquid fertilizer, Feast (9-18-9) on germination, emergence, and seedling growth of winter wheat, (Table 1).

Table 1. Main characteristics of the liquid fertilizers used in the experiments.

Liquid Fertilizer	Weight (lb/gal)	Formulation * N	P	K	S	pH	Characteristics
Solution 32	11.05	32	0	0	0	2.2	32 % of N as $CO(NH_2)_2$, 50% as Ammonium Nitrate and 50 % as Urea.
10-34-0-.9	11.82	10	34	0	.9	6.5	34% P_2O_5, 50% as Orthophosphate and 50% as Polyphosphate. 10 % N as Ammonium.
Thio-Sul	11.11	12	0	0	26		26% S as form of SO_3. 12% N as Ammonium.
Potash Sol	9.76	0	0	15	0	7.0	15% as K_2O from Muriate of Potash.
Feast	11.15	9	18	9	0	7.4	3.2 % of N as Ammoniacal N and 5.8 % as Urea, 18 % of P_2O_5 as Phosphoric acid, and 9 % of K as soluble K_2O.

* Formulation in percent by weight

Stephens winter wheat was used as seed source to conduct the experiments on germination, greenhouse, and field. Stephens is a high-yielding, semidwarf, soft white winter wheat developed and released by the Oregon State University Agriculture Experiment Station in 1977. It is adapted to the winter wheat growing areas of the Pacific Northwest and has a superior yield potential under high rainfall or irrigated conditions.

Seeds of wheat were sized to achieve uniformity by passing them through a # 8 (8/64'' x 3/4''slot) screen and holding on a # 7 (7/64'' x 3/4'' slot). The sized seed was used for all studies.

Randomized Block Design with three replications were used for preliminary experiments on germination, and with four replications for the germination, greenhouse, and field experiments. The mean separation was done using the Tukey's Honestly Significant Difference (HSD) Test (Petersen, 1985).

PRELIMINARY EXPERIMENTS

Germination preliminary experiments were conducted to determine the lower and safe higher rates of the four basic liquid fertilizer sources to be used on the experiments. Each source was tested as pure formulation and at decreasing rates (in solution) until first signs of wheat germination occured, even when detrimental effects on the seed were still quite evident. The upper level of concentration was selected as the highest limit to determine the various levels of treatments at each source.

Fifty seeds were placed in plastic germination boxes, with standard blue germination blotters holding 14 cc of solution. The boxes were placed in the germinator at 20 ^{o}C. Germination, coleoptile length, and seedling dry weight notes were recorded as follows:

Germination: Total germination (%) was recorded at the 7th day.

The seeds were considered germinated when both radicle and coleoptile had appeared, and had a minimum length of 0.5 cm.

Coleoptile length: Emerged coleoptiles (mm per seedling) were measured at the 7th day on the germinated seeds in each box.

Seedling dry weight: Coleoptiles and radicles were separated from seed coat and oven dried at 80 ^{o}C for 36 hours. Dry weight was recorded on the basis of mg per seedling.

The results obtained in these preliminary experiments resulted in several levels of responses. Seven treatments, including a check level without fertilization, were identified (Table 2) for each source of liquid fertilizer to conduct the germination, greenhouse, and field experiments.

Table 2. Treatment levels of germination, greenhouse, and field experiments for each source of liquid fertilizer.

	Liquid Fertilizer									
Treat. Number	Solution 32 $L\ ha^{-1}$	%	10-34-0-.9 $L\ ha^{-1}$	%	Thio-Sul $L\ ha^{-1}$	%	Potash Sol $L\ ha^{-1}$	%	Feast* $L\ ha^{-1}$	%
1	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
2	30	0.25	19	0.16	19	0.16	75	0.63	10	0.08
3	60	0.50	38	0.32	38	0.32	150	1.25	20	0.17
4	90	0.75	75	0.63	75	0.63	300	2.50	30	0.25
5	120	1.00	150	1.25	150	1.25	600	5.00	40	0.33
6	240	2.00	300	2.50	300	2.50	1200	10.00	80	0.67
7	480	4.00	600	5.00	600	5.00	1800	15.00	160	1.33

- $L\ ha^{-1}$: liquid fertilizer rates on liters per hectare basis.
- % : liquid fertilizer rates on solution percent basis.
* Feast (9-18-9), for small grains, is recommended at a rate of 35-45 kg ha^{-1}, (4-5 gal/A), in a row application. The treatments were arbitrarily selected.

GERMINATION EXPERIMENTS

Germination experiments were conducted using the same procedures as preliminary experiments. Total germination, germination rate index, and dry weight of shoots were measured as follow:

Total Germination: Total germination was recorded at the end of the counting period. Five samples were taken at a 24 hour interval of time to observe late germination or detrimental effects on seedlings due to toxic effects.

Germination Rate Index (GRI): GRI was calculated for all the sources and treatments at the time when the check treatment produced two equal counts, using the method described by Maguire (1962), where the number of seedlings emerged per day is divided by the number of days that seeds have been in the germinator. The values obtained at each count are then summed at the end of the test to obtain the GRI according to the following formula:

$$\text{GRI: } \frac{\text{number of normal seedlings}}{\text{days to first count}} + \ldots + \frac{\text{number of normal seedlings}}{\text{days to final count}}$$

Dry Weight of Shoots: Roots and seed coat of wheat seedlings were separated from shoot on the 10th day. Shoots were dried in the oven at 80 ^{o}C for 36 hours. The results are expressed in mg per seedling.

GREENHOUSE EXPERIMENTS

All the experiments were conducted from March to May of 1988.

Soil at a depth of 5 cm was obtained from the site where field experiments were conducted on the fall of 1987. This eliminated one source of variation and allowed correlation of the results on a similar basis. Planting dates, soil analysis and soil moisture content for the greenhouses experiments and for the field experiments is presented in Table 3.

Table 3. Planting dates and characteristics of the soil used in greenhouse and field experiments.

	Greenhouse Experiment	Field Exp 1	Field Exp 2
Planting date	Mar-May, 1988	10/03/87	11/05/87
Soil moisture (%)			
0-5 cm	20.0	7.45	20.15
5-10 cm	----	17.20	20.74
Soil analysis			
N (Total)	0.10	0.11	0.10
P (ppm)	90.00	93.00	105.00
K (ppm)	265.00	316.00	363.00
pH	7.20	6.00	6.90
MO	2.25	2.55	2.40

The soil was placed in 40 x 40 x 5 cm plastic trays. Before potting, the soil moisture content of the soil was adjusted to 20 % by weight. Two rows, 20 cm apart, were hand seeded with 21 seeds of wheat, equivalent to 112 kg ha^{-1}. The fertilizer solution was uniformly applied with an hypodermic needle in the seed row. Following solution application, the seed were covered 3 cm deep. To reduce evaporation, pots were covered with clear plastic until emergence began. The temperature of the greenhouse ranged from 12.2 to 35.5 ^{o}C.

<u>Total Germination</u>: Seven samples of germination were recorded over the development of the experiment. Total germination, expressed in percent, was obtained using the same procedure as in the germinator

experiments.

Emergence Rate Index (ERI): Daily counts of emergence started on the 3rd day for each row in the trays. No plants emerged after 10 days. The emergence counts were converted to percentage, and ERI was calculated using the same method as for the GRI on the germinator experiments.

Dry Weigh of Shoots: Plant tops for shoot dry weight were sampled on the 10th and 20th days after planting, using one row per plot. The shoots were dried at 80 ^{o}C for 36 hr and weighed. The results are presented as mg per shoot.

FIELD EXPERIMENTS

Two field experiments were established during the fall season of 1987 at the Hyslop Experimental Station of Oregon State University, about 11 km northeast of Corvallis, Oregon.

The soil at Hyslop is a Woodburn silt loam (fine, silty, mixed, mesic Aquultic Agrixoroll). This soil is moderately well drained. A mechanical analysis of this soil in the Ap horizon (0-18 cm) is 9 % sand, 70 % silt, and 21 % clay. Table 3 shows planting dates and soil analysis results.

The field was furrowed with 30 cm row separation. Wheat was planted using an Ojyord Type OSD, self propelled riding, cone distribution planter planting 4 rows at a time. Two planting dates were selected to obtain two different environment conditions of field growth.

A planting rate of 112 kg ha^{-1} (100 lb/A) was employed. Seventy one seedlings per linear meter represented 100 % emergence. Plot size was 4 m length and 4 rows at 30 cm apart.

Field Experiment 1, established on Oct 03-1987, was seeded in the open furrow prior to the liquid fertilizer application. The fertilizer was then applied as a solution in a band approximately 8 cm wide in the seed row. The solution was applied with a regular atomizer for herbicide applications. The seeds were immediately covered to a deep of approximately 3 cm. Due to a lack of adequate moisture to obtain a uniform germination and emergence, the experiment was sprinkler irrigated with 4.75 cm of water on Oct 05.

In the field experiment 2 liquid fertilizer was applied on the row before seeding. Seeds were sown using the same planting system as field experiment 1, but were covered with the machine at the time of planting.

Growth measurements were taken from 1 m of each of the two central rows. Seedling counts began when the first plants were visible and continued every other day for 14 days until no further changes were observed in the check treatment.

Total germination, ERI, and dry weight of shoots were recorded using the same procedures as greenhouse experiments.

RESULTS AND DISCUSSION

PRELIMINARY EXPERIMENTS

Results and discussion of preliminary experiments are presented in two parts. Part 1 involves the presentation and discussion of results obtained from germination experiments with decreasing solution concentration rates of the basic liquid fertilizers studied. Part 2 presents the data for coleoptile length and seedling dry weight for selected treatments of the four materials tested.

Part 1. Germination results for the basic liquid fertilizers.

The number of germinated seeds by source and rate are presented in Table 4 and Figure 1. Three distinct concentration levels were visually determined for each source: 1) lethal dose, where no signs of germination were present; 2) critical dose, where concentration levels showed delay or detrimental effects on germination; and 3) safe dose, where the concentration used produced a response similar to the check treatment (Fig. 2).

Solution 32 showed a critical level at 0.25 % of solution concentration, equivalent to 30 L ha^{-1} of product or to an application of 13 kg of N ha^{-1}. The lethal level occured at 4 % of solution concentration, equivalent to 481 L ha^{-1} of product or 204 kg of N ha^{-1}.

Equal critical and lethal levels of solution concentrations were found for the 10-34-0-.9 and Thio-Sul sources. Both materials responded in a similar manner. Critical and lethal levels were found at 0.08 and 5 % of solution concentration, equivalent to 9.6 and 601 L ha^{-1} of product, respectively. As shown in Table 1, both sources have a

Table 4. Concentration, Product, Germination, and Rate of Nutrients of the Basic Liquid Fertilizers.

		SOLUTION 32		10-34-0-.9				THIO-SUL			POTASH SOL	
CONCENT.	PRODUCT	Germin.	R. of N.*	Germin.		R. of N.*		Germin.	R. of N.*		Germin.	R. of N.*
(%)	lt/ha	(%)	N	(%)	N	P	S	(%)	N	S	(%)	K
100	12,014.0	0.00	5106	0.00	1706	5804	154	0.00	1922	4169	0.00	2114
75	9,010.0	0.00	3829	0.00	1279	4353	115	0.00	1441	3127	0.00	1585
50	6,007.0	0.00	2553	0.00	853	2902	77	0.00	961	2085	0.00	1057
25	3,004.0	0.00	1277	0.00	427	1451	39	0.00	481	1042	0.00	529
20	2,403.0	0.00	1021	0.00	341	1161	31	0.00	384	834	0.00	423
15	1,802.0	0.00	766	0.00	256	871	23	0.00	288	625	9.33 +	317
10	1,201.0	0.00	510	0.00	171	580	15	0.00	192	417	86.00	211
5	601.0	0.00	255	28.00 +	85	290	8	36.67 +	96	209	97.33	106
4	481.0	5.33 +	204	59.33	68	232	6	28.67	77	167	96.00	85
3	360.0	75.33	153	66.67	51	174	5	28.67	58	125	94.00 -	63
2	240.0	92.00	102	86.00	34	116	3	47.33	38	83	98.67	42
1	120.0	90.67	51	90.00	17	58	2	54.00	19	42	97.33	21
.75	90.0	95.33	38	95.33	13	43	1	80.00	14	31	94.00	16
.50	60.0	90.66	26	90.67	9	29	1	89.33	10	21	96.00	11
.25	30.0	96.00 -	13	96.00	4	14	0	92.00	5	10	98.00	5
.10	12.0	96.00	5	95.33	2	6	0	97.33	2	4	98.00	2
.08	9.6	90.66	4	94.67 -	1	5	0	96.00 -	2	3	--	--
.06	7.2	93.33	3	95.33	1	3	0	96.00	1	2	--	--
.04	4.8	96.66	2	94.67	1	2	0	98.67	1	2	--	--
.02	2.4	98.67	1	98.00	0	1	0	95.33	0	1	--	--
.00	0.0	98.00	0	98.00	0	0	0	95.33	0	0	98.00	0

* Rate of Nutrients in kg ha-1

+ Indicate the upper concentration level at which signs of germination occurs (lethal level).

- Indicate the upper concentration level at which germination seems to be normal (critical level)

+ and - are visual observations taken at the 10th days from seeding.

Figure 1. Wheat germination as affected by sources and rates of liquid fertilizers.

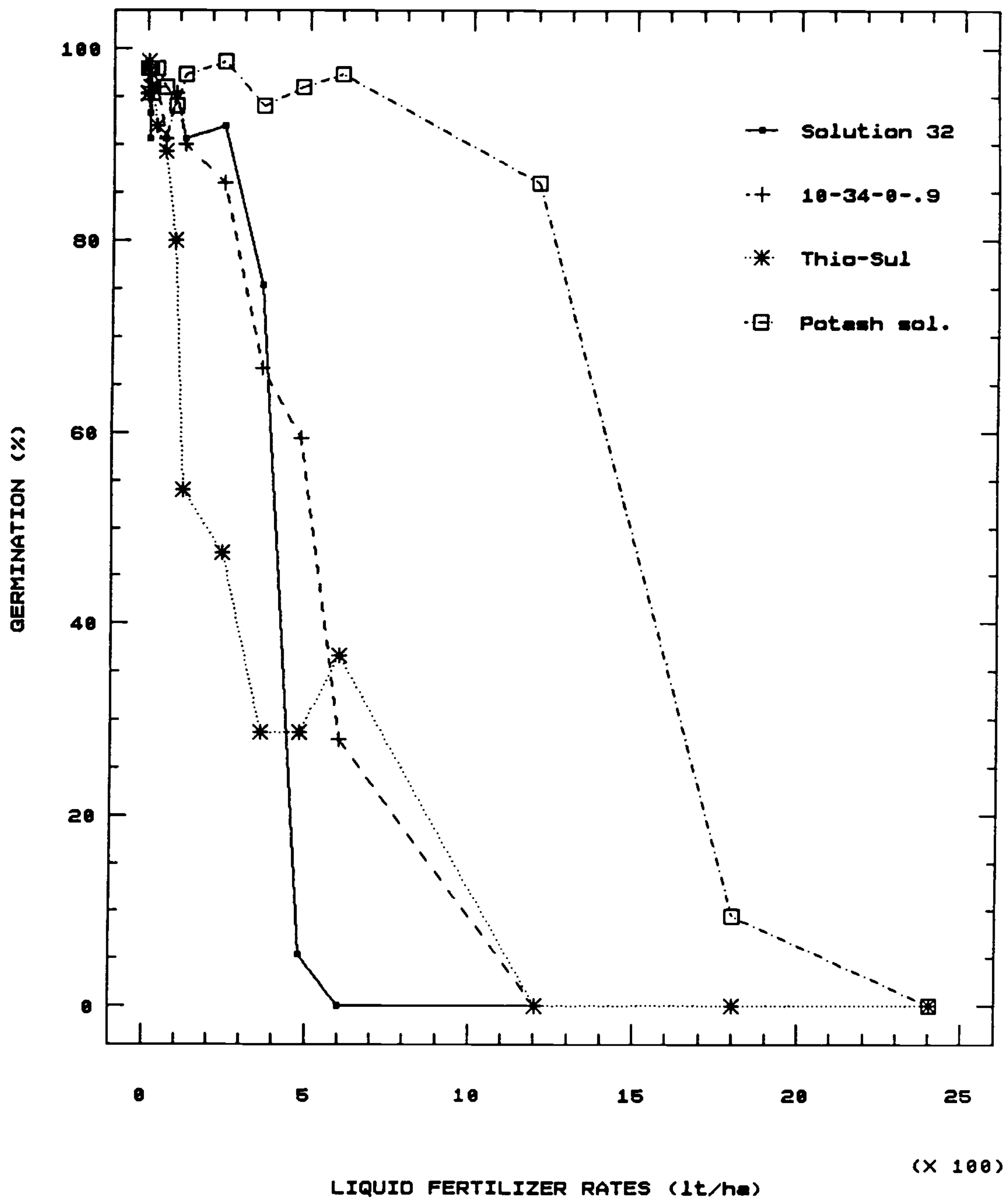
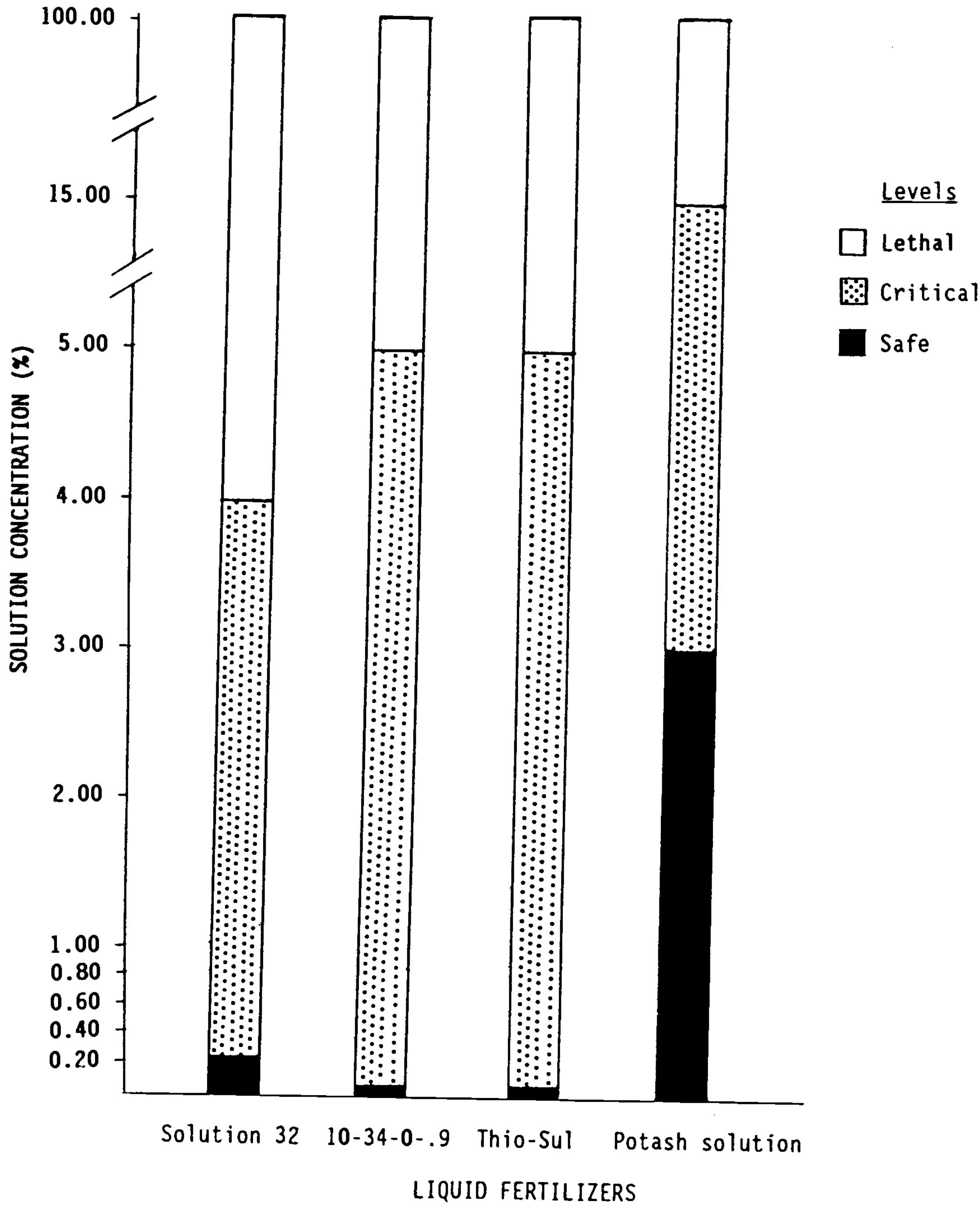


Figure 2. Lethal, Critical, and Safe Solution Concentration Levels for the Liquid Fertilizer Sources.

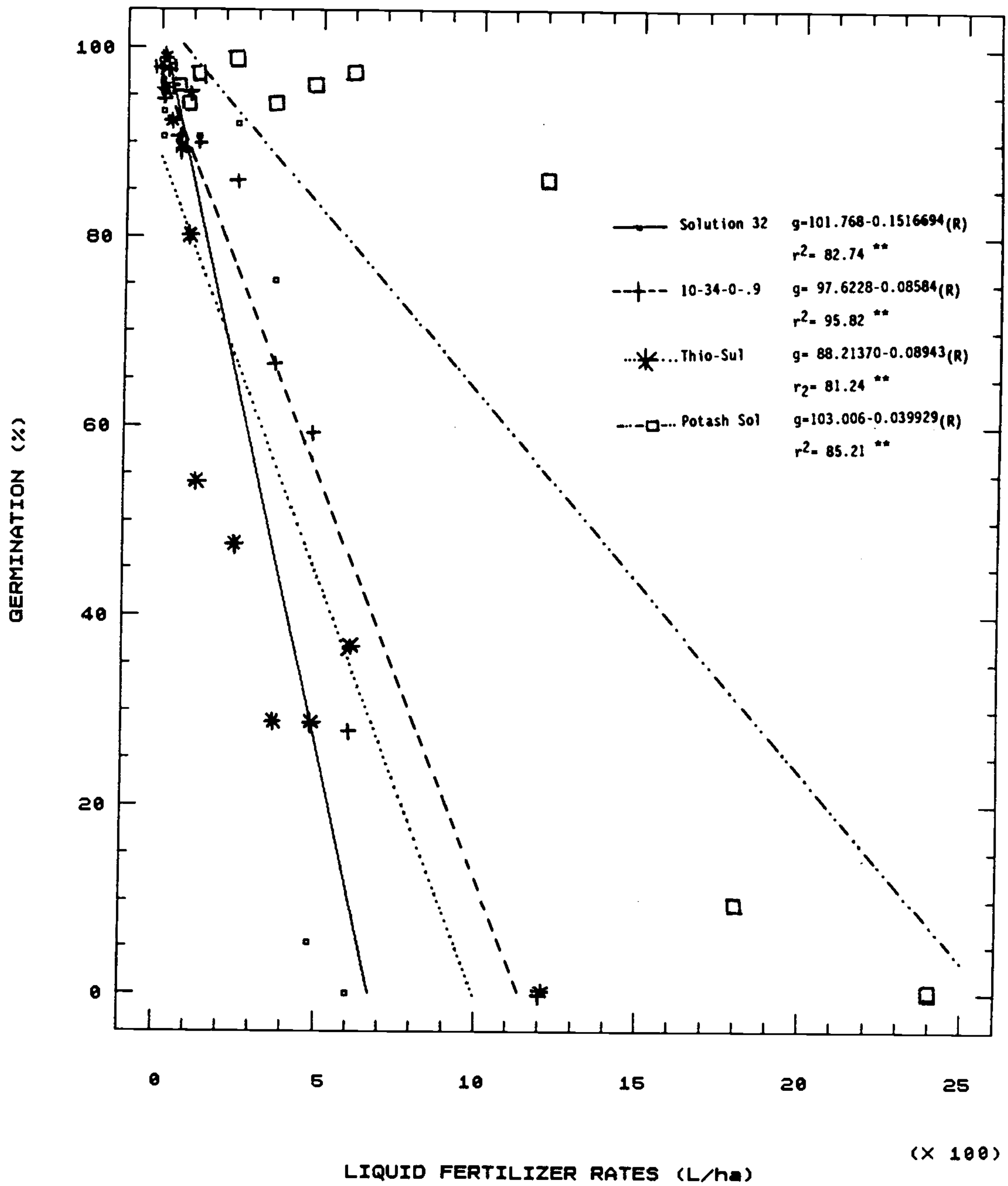


different constitution, but nitrogen is present in both sources at about the same percentage. Critical and lethal doses for nitrogen in both sources are much lower than those found for Solution 32, which may indicate that both phosphorus and/or sulfur had independent negative effects on germination, or it may indicate that small doses of nitrogen, in combination with another element, has a strong influence on delaying or preventing germination.

Potassium, among the nutrients studied, was the element tolerated at higher solution concentrations by the seed. Critical levels were noted at 3 % of solution concentration, equivalent to 360 L ha^{-1} of product or 63 kg of K ha^{-1}. Lethal levels were found at a 15 % of solution concentration rate, equivalent to 1802 L ha^{-1} of product, an application of 317 kg of K ha^{-1}.

Simple regression analysis of the data for each source indicated that 80 % germination, in laboratory tests, can be obtained at solution concentration rates of 143.5, 205.28, 91.85, and 576.17 L ha^{-1} for Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, respectively. These values were found in the visual critical level recorded, where normal growth of the seedling is delayed or affected (Table 4 and Fig. 3). However as the rate of liquid fertilizer source increased, total germination decreased in a linear manner. For each 10 L ha^{-1} of product applied, germination decreased by 1.52, 0.86, 0.89, and 0.40 % for Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, respectively.

Figure 3. Regression of germination on the liquid fertilizer sources.



Part 2. Coleoptile length and dry weight results for the liquid fertilizer sources.

Selected treatments were studied for each source to determine the exact point were no difference would be found between the check treatment and the solution concentration levels. The ranges given in Table 4 and Fig. 2 for safe, critical, and lethal levels were taken as visual observations, subsequently more sensitive parameters, such as coleoptile length and seedling dry weight were measured.

The results obtained for Solution 32 (Table 5), agree with the visual critical level observed for germination (Table 4). Coleoptile length and seedling dry weight were similar to the check treatment without fertilizer at rates up to 0.2 % of solution concentration, equivalent to applications of 24 L ha^{-1} of product (10.2 kg of N ha^{-1}). Both parameters were highly sensitive with increasing Solution 32 doses within the ranges studied.

There were no significant differences in the 10-34-0-.9 fertilizer source at the 5 % level among the treatments studied for coleoptile length (Table 6), even when differences were present at the 10 % level. Seedling dry weight was more sensitive for detecting differences among the treatments. The critical level found for germination in the preliminary experiments was slightly higher than those found for seedling dry weight, 0.08 versus 0.06 percent, solution concentration, respectively.

Thio-Sul responses for coleoptile length and seedling dry weight are presented in Table 7. Both parameters were more sensitive than germination alone to detect significant differences among the rates studied. The check treatment had higher coleoptile length and higher seedling dry weight than any treatment with Thio-Sul. This indicates

Table 5. Average means for coleoptile length and seedling dry weight for the preliminary experiment with Solution 32.

Solution Concentration (%)	Product L ha^{-1}	Coleoptile Length (mm)	Seedling Dry Weight (mg)
0.0	0	45.31 a*	10.65 a
0.1	12	48.82 a	11.29 a
0.2	24	41.83 ab	9.35 ab
0.3	36	34.32 bc	8.37 bc
0.4	48	29.87 cd	8.10 bcd
0.5	60	28.71 cd	7.65 bcd
0.6	72	22.22 d	7.13 cd
0.7	84	21.40 de	6.63 cd
0.8	96	21.16 de	6.19 cde
0.9	108	20.58 de	6.39 de
1.0	120	15.58 e	4.99 e

* Values followed by the same letter within each column do not differ at the 5 % level of significance (Tukey's HSD Test).

Table 6. Average means for coleoptile length and seedling dry weight for the preliminary experiment with 10-34-0-.9.

Solution Concentration (%)	Product L ha^{-1}	Coleoptile Length (mm)	Seedling Dry Weight (mg)
0.00	0.0	42.67 a*	10.85 a
0.02	2.4	40.69 a	10.10 ab
0.04	4.8	36.84 a	9.67 ab
0.06	7.2	38.88 a	9.60 ab
0.08	9.6	35.47 a	9.11 b
0.10	12.0	36.75 a	9.14 b

* Values followed by the same letter within each column do not differ at the 5 % level of significance (Tukey's HSD Test).

that the association of nitrogen and sulfur applied even at low rates can have adverse effects on the more sensitive parameters measured.

The results for the Potassium rates are presented in Table 8. Even when the treatments include higher rates of solution concentration, the response was similar to the one found with Thio-Sul, that is, the total germination is not as sensitive as coleoptile length or seedling dry weight at lower rates of fertilizer when the solution is directly applied to seeds.

The results of these preliminary trials on direct application to the seed were used to determine the levels of treatments for the germination, greenhouse, and field experiments.

Table 7. Average means for coleoptile length and seedling dry weight for the preliminary experiment with Thio-Sul.

Solution Concentration (%)	Product L ha^{-1}	Coleoptile Length (mm)	Seedling Dry Weight (mg)
0.00	0.0	42.67 a*	10.85 a
0.02	2.4	30.52 b	8.52 b
0.04	4.8	29.33 b	7.70 bc
0.06	7.2	26.13 b	7.79 bc
0.08	9.6	22.57 b	7.03 bc
0.10	12.0	23.06 b	7.47 c

* Values followed by the same letter within each column do not differ at the 5 % level of significance (Tukey's HSD Test).

Table 8. Average means for coleoptile length and seedling dry weight for the preliminary experiment with Potash solution.

Solution Concentration (%)	Product L ha^{-1}	Coleoptile Length (mm)	Seedling Dry Weight (mg)
0.00	0	41.15 a*	11.73 a
2.50	300	26.98 b	8.83 b
2.75	330	24.50 b	8.07 bc
3.00	360	17.70 cd	6.86 bc
3.25	390	20.95 bc	7.46 bc
3.50	420	17.99 cd	6.92 bc
3.75	451	14.28 d	6.34 c
4.00	481	16.32 cd	6.81 bc
4.25	511	17.20 cd	6.84 bc
4.50	541	15.13 cd	6.57 c

* Values followed by the same letter within each column do not differ at the 5 % level of significance (Tukey's HSD Test).

SOLUTION 32 EXPERIMENTS

Analysis of variance were used to obtain estimates of significance for the levels used for the environment studied on total germination, ERI, and seedling dry weight. The samples for dry weight were taken at 10 and 20 days from planting for germination and greenhouse experiments, and at 10 and 20 days from first emergence for field experiments. Significant differences were found for each of the parameters studied in all environments except in field experiment 1 (Table 9).

Wheat seeds did not germinate in germination experiments at the highest rate of Solution 32, 4 % concentration solution level (Table 10), as compared with the 5.33 % germination obtained in the preliminary experiments (Table 4) for the same rate. This indicates that lethal level for wheat seed exposed to direct imbibition of solution 32 source is around 481 L ha^{-1} of product or 204 kg of N ha^{-1}. In the greenhouse and field experiment 2, even when total germination was higher for the higher rate of Solution 32, it was significatively different from the rest of the treatments (Table 10). No differences were found in the field experiment 1 for all the parameters studied. The growing conditions present at planting were markedly different for each environment. Germination experiment had 20 ^{o}C constant temperature. Greenhouse and field experiments, with soil as growing medium, had different regimens of temperature and moisture interacting. These environments provide variable soil moisture and seed bed conditions with which the farmers could be confronted.

Seed bed conditions for the field experiment 1 were generally poor; initially it had low soil moisture (7,45 %) and high temperature.

Table 9. Analysis of variance for total germination, emergence rate index (ERI) and seedling dry weight for Solution 32.

			PR F			
Environment	Source of Variation	df	Total Germinat.	Emergence Rate Index	Dry wt. 10 ds	Dry wt. 20 ds
GERMINATION						
	Total	27				
	Replic.	3	NS	NS	NS	--
	Rates	6	**	**	**	--
	Error	18				
	C.V.		15.66	27.31	27.43	--
GREENHOUSE						
	Total	27				
	Replic.	3	NS	*	NS	*
	Rates	6	**	**	**	**
	Error	18				
	C.V.		13.48	18.01	20.05	17.17
FIELD EXP. # 1						
	Total	27				
	Replic.	3	NS	NS	@	*
	Rates	6	@	@	NS	NS
	Error	18				
	C.V.		11.43	11.83	10.58	24.63
FIELD EXP. # 2						
	Total	27				
	Replic.	3	*	NS	NS	NS
	Rates	6	*	**	**	**
	Error	18				
	C.V.		7.16	7.72	11.40	16.33

**, *, @ -- significant at 0.01, 0.05, and 0.10 probability levels, respectively.
NS -- nonsignificant.
C.V. -- Coefficient of Variation (%)

Table 10. Means for total germination and ERI for the Solution 32 source.

Solution Concent. (%)	Product L ha^{-1}	Total Germination (%) Germin.	Greenhouse	Field 1	Field 2	Emergence Rate Index Germin.	Greenhouse	Field 1	Field 2
0.00	0	90.00 a*	85.10 a	74.38 a	87.68 ab	27.08 a	22.83 a	6.91 a	8.00 a
0.25	30	97.50 a	89.30 a	67.03 a	85.93 ab	26.92 a	24.11 a	5.82 a	7.75 ab
0.50	60	89.00 ab	76.18 a	82.07 a	84.70 ab	21.90 ab	20.69 a	7.37 a	7.89 a
0.75	90	91.00 ab	77.38 a	76.65 a	87.85 ab	22.05 ab	19.87 a	6.55 a	8.16 a
1.00	120	69.00 bc	72.63 a	85.75 a	91.70 a	13.73 bc	19.45 a	7.35 a	8.22 a
2.00	240	51.00 c	70.85 a	75.60 a	77.88 ab	9.88 cd	17.85 a	6.22 a	7.08 ab
4.00	480	0.00 d	27.40 b	69.30 a	75.07 b	0.00 d	5.40 b	6.13 a	6.45 b

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

Since the seed was hand covered after planting the experiment, some remained on the soil surface or at different depths. Conway (1977) found that the most negative effects on stand establishment occurs when soil temperature is high, soil moisture content is low, and deep planting is used. It seems apparent than those factors, acting on less controllable conditions, affects total germination much more than it affects germination due to applied rates of liquid fertilizers (97.6, 90.36, 84.00, and 87.82 % total germination-emergence for checks treatment at germination, greenhouse, field experiment 1, and field experiment 2, respectively).

Levels up to 90, 240, 480, and 240 L ha^{-1} were comparable on total germination and ERI to the treatment without fertilizer for germination, greenhouse, field experiment 1, and field experiment 2, respectively (Table 10).

Seedling dry weight response (Table 11), was also related to the other parameters. In the greenhouse experiments at 20 days the response of the check treatment was significatively lower than all the fertilizer rates up to 240 L ha^{-1} of product.

Percentage of germinated or emerged plants by rate and time of counting for the different environments studied are presented in Fig. 4. Plants developed quickly and uniformly with relatively little change in the number of germinated or emerged plants after the third sampling date, which correspond to five days after planting on germination and greenhouse, and 15 days after sowing for the field experiments. This was especially true for the check treatment and for those with lower rates of liquid fertilizer.

Regression analysis of germination on Solution 32 rates for the environments studied are presented in Fig. 5. Steep slopes and higher determination coefficients (r^2) are observed on germination and greenhouse experiments.

Table 11. Means for seedling dry weight (mg) for Solution 32 source.

Solution Concent. (%)	Product L ha^{-1}	Germination	Greenhouse		Field 1		Field 2	
		10 days	10 days	20 days	10 days	20 days	10 days	20 days
0.00	0	4.09 ab*	7.25 ab	28.09 b	19.23 a	60.90 a	8.81 ab	20.47 a
0.25	30	4.52 a	10.22 a	54.23 a	18.33 a	54.30 a	9.54 ab	17.08 ab
0.50	60	3.93 ab	9.48 a	51.89 a	17.10 a	68.83 a	9.10 ab	20.97 a
0.75	90	3.45 ab	9.27 a	56.07 a	19.87 a	55.29 a	8.98 ab	18.47 a
1.00	120	2.43 b	8.78 a	47.01 a	17.93 a	46.62 a	10.06 a	17.74 ab
2.00	240	2.23 b	8.80 a	48.57 a	16.75 a	55.04 a	7.63 bc	19.63 a
4.00	480	0.00 c	4.41 b	14.60 b	17.38 a	58.83 a	5.81 c	11.48 b

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

Figure 4. Percentage of germinated-emerged wheat plants as affected by rate of Solution 32 liquid fertilizer source and time for germination, greenhouse and field experiments.

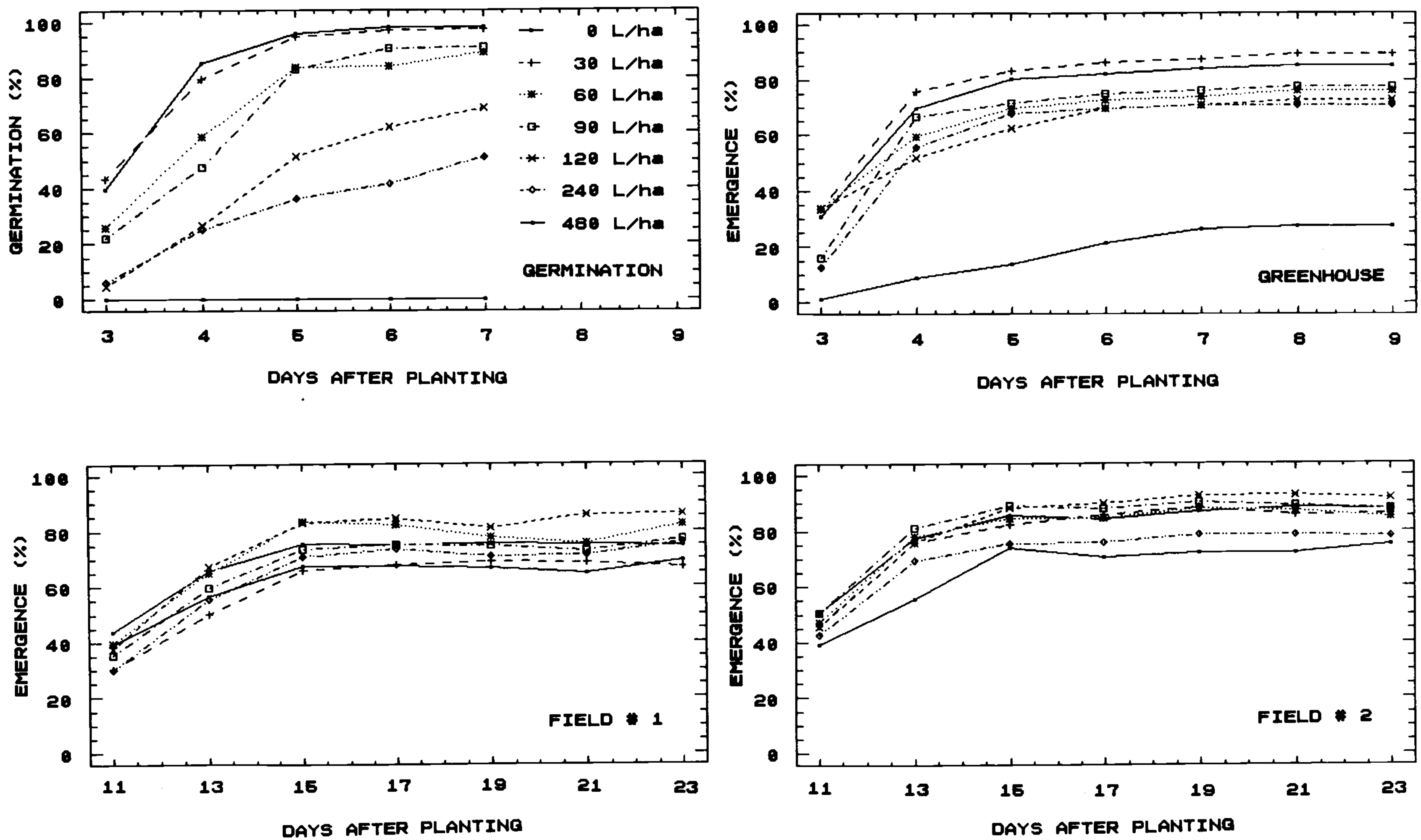
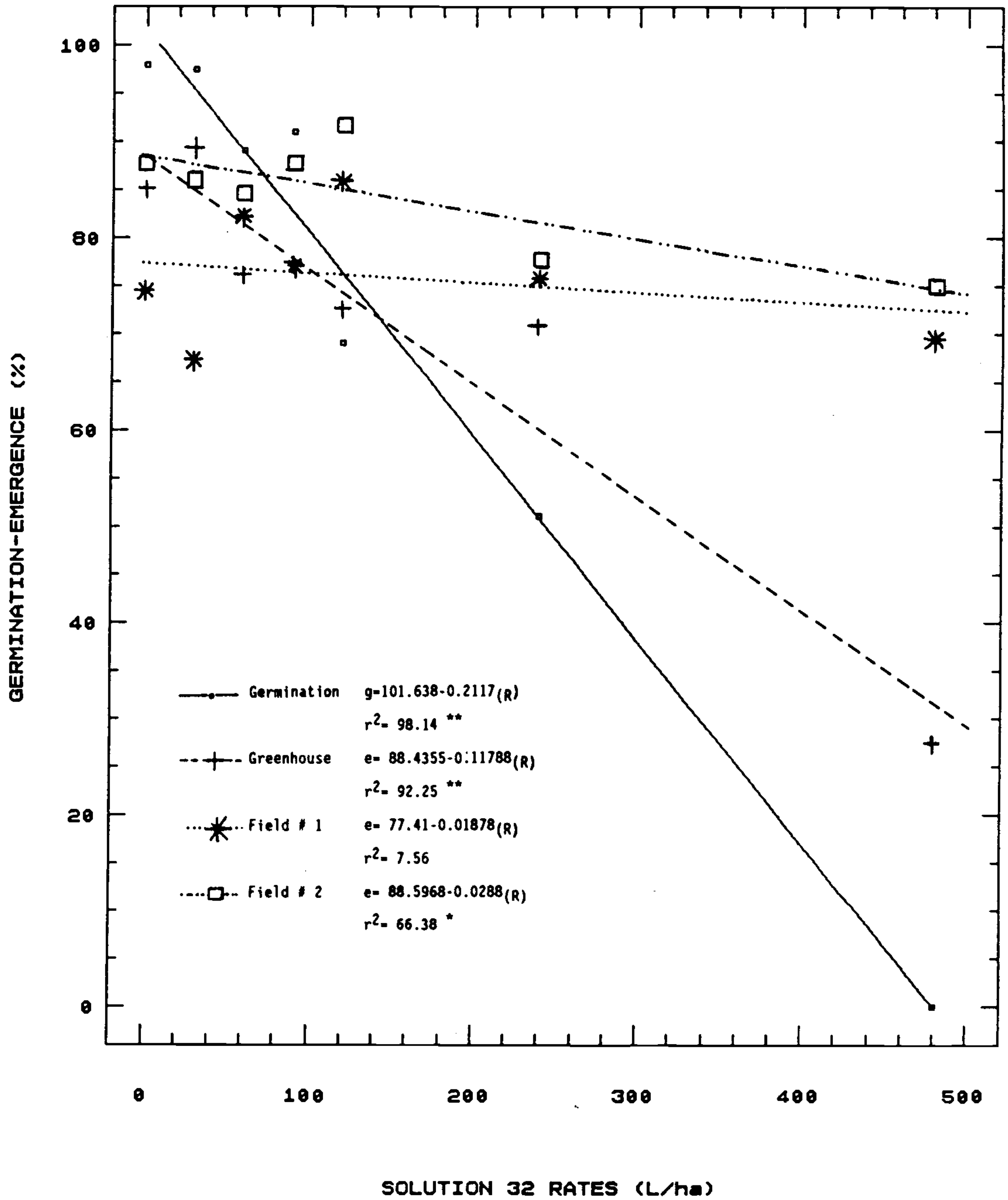


Figure 5. Regression of germination on Solution 32 rates.



10-34-0-.9 EXPERIMENTS

Analysis of variance for total germination, ERI, and dry weight are presented in Table 12. Wheat seeds tolerated 10-34-0-.9 at higher rates than Solution 32. Highly significant differences were found among the treatments for all the parameters studied in the germination experiments and for germination alone in greenhouse experiments. Dry weight at 10 days was significant in greenhouse and field experiment 2. The rest of the analysis were nonsignificant or gave low significance results, such as a 0.10 probability level found for dry weight at 20 days in the greenhouse experiments.

At the higher concentration of 5 %, no germination occurred (Table 13), as compared with 28.00 % found in preliminary experiments for the same concentration levels (Table 4). A lethal concentration seems to be in a very narrow range between signs of germination and total restriction of seed growth. Germination occurs at higher rate in greenhouse experiments, being significatively different from all treatments up to 150 L ha^{-1} of product.

In field experiments 1 and 2, no significant differences were found among the treatments studied. The higher doses had equal response to the rest of the treatments for total emergence, ERI, and dry weight, except for dry weight at 10 days in field experiment 2 (Table 14). These results in the field experiments showed unusually high, safe ranges of fertilizer applications. The 5 % solution concentration is equivalent to an application of 600 L ha^{-1} of product or the incorporation of 85, 290, and 8 kg ha^{-1} of N, P, and S respectively; much higher than any dose of starter fertilizer that would be applied by farmers.

Table 12. Analysis of variance for total emergence, ERI, and seedling dry weight for 10-34-0-.9 source.

			PR F			
Environ- ment	Source of variation	df	Total Germin.	Emergence Rate Index	Dry wt. 10 days	Dry Wt. 20 days
GERMINATION						
	Total	27				
	Replicat.	3	NS	NS	NS	--
	Rates	6	**	**	**	--
	Error	18				
	C.V.		8.63	10.45	14.08	--
GREENHOUSE						
	Total	27				
	Replicat.	3	NS	*	NS	*
	Rates	6	**	NS	*	@
	Error	18				
	C.V.		15.19	34.41	21.00	27.56
FIELD # 1						
	Total	27				
	Replicat.	3	NS	NS	**	NS
	Rates	6	NS	NS	NS	NS
	Error	18				
	C.V.		35.38	34.41	10.64	23.53
FIELD # 2						
	Total	27				
	Replicat.	3	@	@	NS	*
	Rates	6	NS	NS	*	NS
	Error	18				
	C.V.		13.31	11.81	5.29	8.26

**, *, @ -- significant at 0.01, 0.05, and 0.10 probability levels, respectively.
NS -- nonsignificant.
C.V.-- Coefficient of Variation (%)

Table 13. Means for total germination and ERI for 10-34-0-.9 source.

Solution Concent. (%)	Product L ha^{-1}	Total Germination (%)				Emergence Rate Index			
		Germin.	Greenhouse	Field 1	Field 2	Germin.	Greenhouse	Field 1	Field 2
0.00	0	98.50 a*	94.65 a	91.17 a	86.97 a	28.45 a	23.13 a	8.20 a	7.74 a
0.16	19	98.50 a	94.05 a	82.07 a	88.55 a	28.25 a	23.78 a	6.91 a	7.61 a
0.32	38	92.00 a	94.05 a	62.47 a	91.70 a	24.95 ab	22.05 a	5.43 a	8.27 a
0.63	75	95.50 a	93.45 a	81.90 a	83.47 a	23.70 b	21.86 a	6.90 a	7.75 a
1.25	150	48.00 b	86.30 a	71.93 a	94.50 a	8.18 c	18.57 ab	6.10 a	8.54 a
2.50	300	10.50 c	74.43 ab	72.97 a	81.20 a	1.33 d	14.80 bc	6.28 a	7.44 a
5.00	600	0.00. c	48.20 b	75.43 a	88.20 a	0.00 d	8.28 c	6.88 a	7.91 a

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

Once applied to the soil, phosphorus, and also potassium, do not move far because they are held tightly by the soil particles. Barber (1978) stated that, even with favorable conditions, less than 10 percent of the applied phosphate and 20-40 % of applied potassium will reach the root during one crop season. This reason, plus the fact that fertilizers on field experiments were applied on a 8 cm band over the seeds, can explain the higher safe rates of 10-34-0-.9 concentration levels that can be used on wheat seeds without delaying or affecting germination under field circumstances.

Ranges of 10-34-0-.9 up to 75, 300, 600, and 600 L ha^{-1} were comparable to the check treatment without fertilizer for total germination-emergence at the germination, greenhouse, field 1, and field 2 environments, respectively. ERI was comparable to the check treatment at 10-34-0-.9 ranges up to 38, 150, 600, and 600 L ha^{-1} for the same order of locations (Table 13).

Large differences of seedling dry weight were found only in germination experiments, where the treatment without fertilization had seedling dry weight significatively higher than all treatment containing fertilizer solutions. All the treatments were equal to the check treatment, with exception of seedling dry weight at 10 days at greenhouse and field 2 experiments for the higher rate of 10-34-0-.9 (Table 14).

Percentage of germinated-emerged seeds by rate of 10-34-0-.9 and time of sampling are presented on Fig. 6 for all the environments studied. The pattern for growth and emergence was similar to those found on Solution 32, where most of the total germination reached its maximum at the 3rd sampling date.

Regression analysis and linear model for 10-34-0-.9 responses at the location studied are presented in Fig. 7. High values for r^2 were found only for germination and greenhouse environments.

Table 14. Means for seedling dry weight (mg) for 10-34-0-.9 source.

Solution Concent. (%)	Product L ha^{-1}	Germination	Greenhouse		Field 1		Field 2	
		10 days	10 days	20 days	10 days	20 days	10 days	20 days
0.00	0	4.59 a*	8.60 ab	26.14 a	17.15 a	51.96 a	9.99 ab	21.56 a
0.16	19	3.65 b	10.51 a	40.19 a	17.40 a	57.20 a	9.66 ab	22.34 a
0.32	38	2.51 c	9.05 ab	43.18 a	17.31 a	55.36 a	9.00 ab	18.97 a
0.63	75	2.52 c	10.61 a	51.29 a	18.78 a	62.53 a	9.53 ab	19.47 a
1.25	150	1.56 d	10.51 a	45.92 a	17.58 a	51.07 a	10.14 a	19.84 a
2.50	300	1.40 d	8.57 ab	52.48 a	20.26 a	64.99 a	9.54 ab	18.47 a
5.00	600	0.00 e	6.00 b	37.70 a	19.86 a	73.70 a	8.94 b	20.96 a

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

Figure 6. Percentage of germinated-emerged wheat plants as affected by rate of 10-34-0-.9 liquid fertilizer source and time for germination, greenhouse and field experiments.

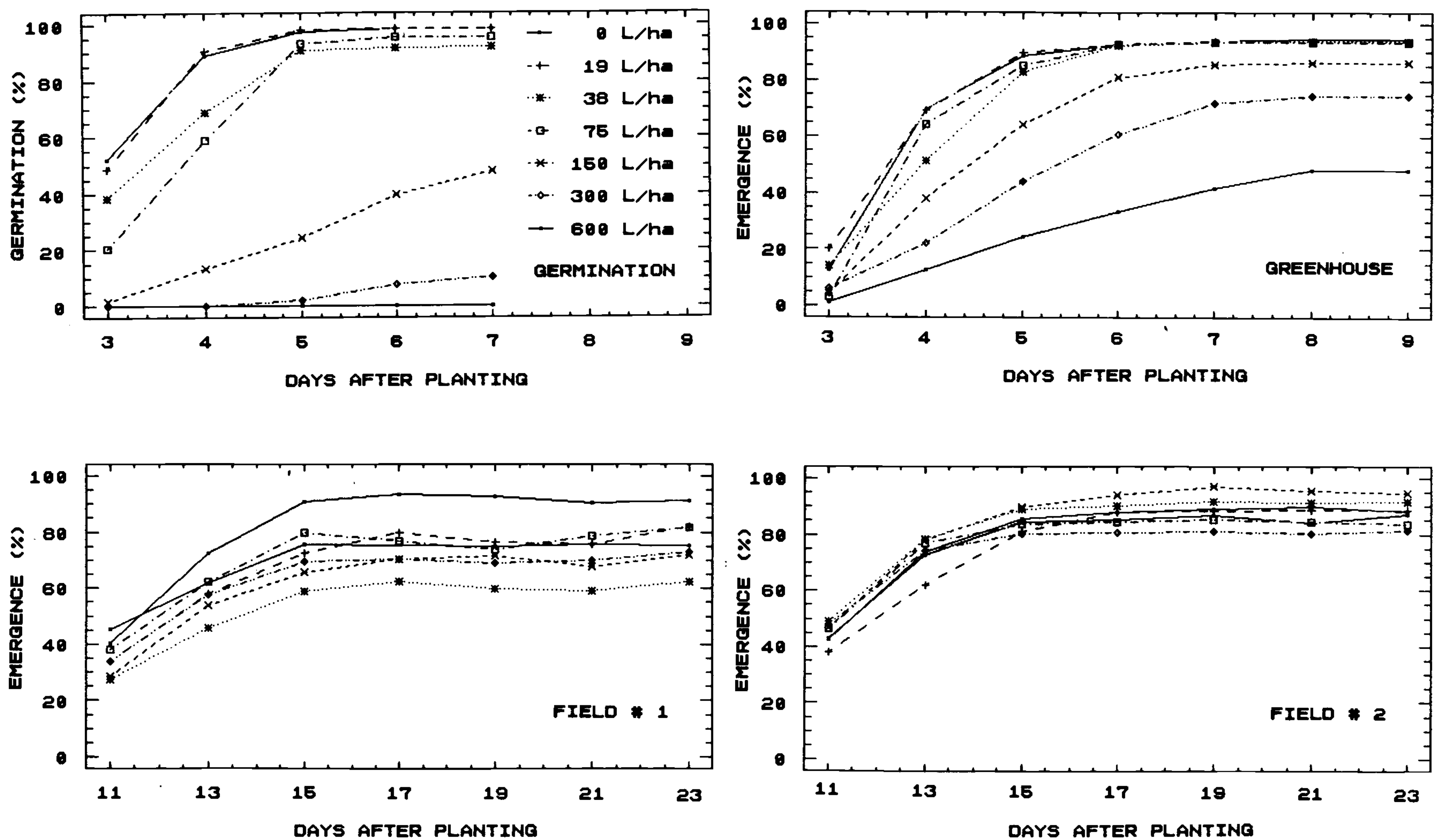
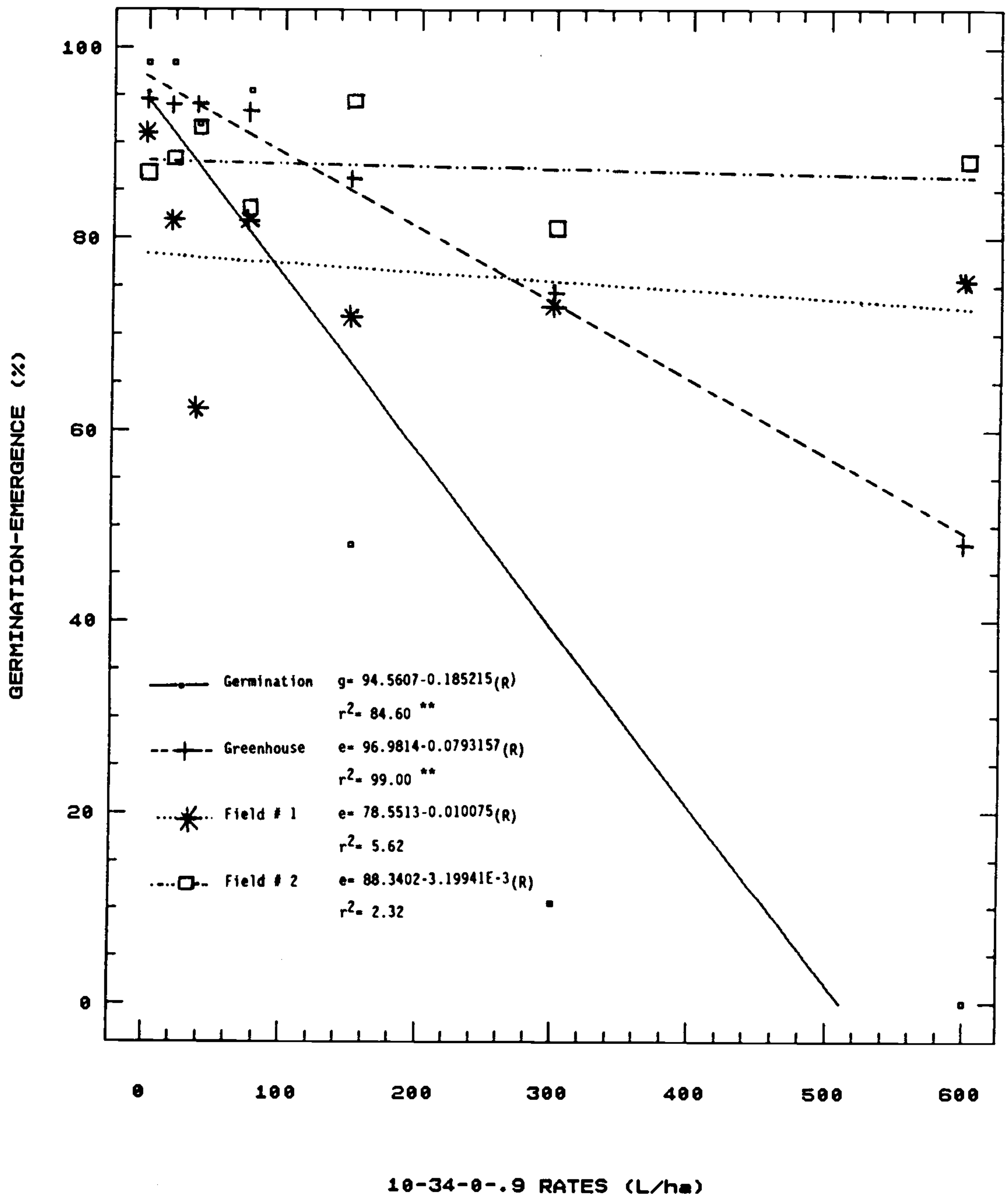


Figure 7. Regression of germination on 10-34-0-.9 rates.



THIO-SUL EXPERIMENTS

Table 15 presents analysis of variance over environments studied for total germination, ERI, and seedling dry weight at 10 and 20 days. Highly significant differences were found for all the variables in germination and greenhouse experiments. Fertilizer levels for total germination and ERI were not significatively different from the check without fertilizer in both field 1 and field 2 experiments, while seedling dry weight at 10 days was highly significant only in field experiment 1, and seedling dry weight at 20 days was significant in field experiment 2.

No germination was obtained at the 5 % concentration level (Table 16), as compared with the 36.67 % germination obtained at the same level in the preliminary experiments (Table 4). Again, lethal levels seems to be very narrow at the higher concentrations studied. Thio-Sul emergence at 5 % concentration level was also very restrictive in greenhouse experiments, where only 1.8 % of the seeds emerged, with practically zero ERI and significatively lower seedling dry weight than many treatments with lower fertilizer levels of Thio-Sul (Tables 16 and 17).

Total germination and ERI had similar response to the check treatment to Thio-Sul doses up to 19, 75, 600, and 600 L ha^{-1} for germination, greenhouse, field 1, and field 2 experiments, respectively (Table 16).

Both seedling dry weight at 10 and 20 days had larger differences in the germination and greenhouse experiments, while in field experiments seedling dry weight was the same for all the treatments with exception of at 10 days in field experiment 1 (Table 17).

Figure 8 presents the percentage of germinated-emerged plants at

Table 15. Analysis of variance for total emergence, ERI, and seedling dry weight for Thio-Sul source.

			PR F			
Environ-ment	Source of variation	df	Total Germin.	Emergence Rate Index	Dry wt. 10 days	Dry wt. 20 days
GERMINATION						
	Total	27				
	Replicat.	3	NS	NS	NS	--
	Rates	6	**	**	**	--
	Error	18				
	C.V.		8.67	10.34	31.64	--
GREENHOUSE						
	Total	27				
	Replicat.	3	NS	NS	NS	@
	Rates	6	**	**	**	**
	Error	18				
	C.V.		16.72	18.17	27.35	27.35
FIELD # 1						
	Total	27				
	Replicat.	3	NS	NS	@	@
	Rates	6	NS	NS	**	NS
	Error	18				
	C.V.		12.32	12.12	9.02	25.10
FIELD # 2						
	Total	27				
	Replicat.	3	NS	NS	NS	NS
	Rates	6	NS	NS	NS	*
	Error	18				
	C.V.		14.06	14.95	12.90	13.04

**, *, @ -- significant at 0.01, 0.05, and 0.10 probability levels, respectively.
NS -- nonsignificant.
C.V. -- Coefficient of Variation (%)

Table 16. Means for total germination and ERI for Thio-Sul source.

Solution Concent. (%)	Product L ha^{-1}	Total Germination (%)				Emergence Rate Index			
		Germin.	Greenhouse	Field 1	Field 2	Germin.	Greenhouse	Field 1	Field 2
0.00	0	97.50 a*	94.05 a	84.18 a	88.03 a	29.60 a	27.90 a	7.30 a	8.23 a
0.16	19	95.50 ab	91.68 ab	74.90 a	82.60 a	26.98 a	26.46 a	7.02 a	7.70 a
0.32	38	85.50 b	71.43 b	85.05 a	90.65 a	20.83 b	14.85 b	7.33 a	8.47 a
0.63	75	56.00 c	90.50 ab	70.88 a	86.28 a	12.25 c	23.17 a	6.28 a	8.08 a
1.25	150	32.50 d	33.95 c	78.75 a	98.70 a	6.70 d	4.15 c	7.35 a	9.14 a
2.50	300	14.00 e	13.13 c	79.45 a	79.10 a	2.60 e	0.76 c	6.85 a	7.19 a
5.00	600	0.00 f	1.80 d	74.03 a	74.20 a	0.00 e	0.00 c	6.45 a	6.76 a

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

Table 17. Means for seedling dry weight (mg) for Thio-Sul source.

Solution Concent. (%)	Product L ha^{-1}	Germination 10 days	Greenhouse 10 days	Greenhouse 20 days	Field 1 10 days	Field 1 20 days	Field 2 10 days	Field 2 20 days
0.00	0	3.42 ab*	11.60 ab	33.49 ab	20.35 a	49.01 a	9.07 a	18.72 a
0.16	19	3.74 a	13.28 a	45.70 a	20.28 a	61.15 a	9.44 a	16.28 a
0.32	38	2.80 ab	8.28 b	40.55 ab	18.94 ab	61.92 a	8.65 a	20.59 a
0.63	75	2.06 bc	11.27 ab	50.22 a	19.84 a	61.71 a	10.06 a	19.68 a
1.25	150	1.04 cd	3.18 c	34.01 ab	16.57 ab	62.67 a	9.27 a	18.92 a
2.50	300	1.06 cd	1.83 c	20.99 bc	19.55 a	49.70 a	8.55 a	15.16 a
5.00	600	0.00 d	0.25 c	5.13 c	15.43 b	51.77 a	10.80 a	15.54 a

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

the environment studied and for the time and rates of Thio-Sul. Large differences were observed in the germination and greenhouse experiments, while a more uniform growing pattern was observed for all treatments in both field 1 and field 2 experiments.

Regression analysis and linear model of total germination on Thio-Sul rates are presented in Fig. 9. A similar slope can be observed for both germination and greenhouse experiments, while the field experiment regression line has a similar pattern to the rest of the sources studied.

Figure 8. Percentage of germinated-emerged wheat plants as affected by rate of Thio-Sul liquid fertilizer source and time for germination, greenhouse and field experiments.

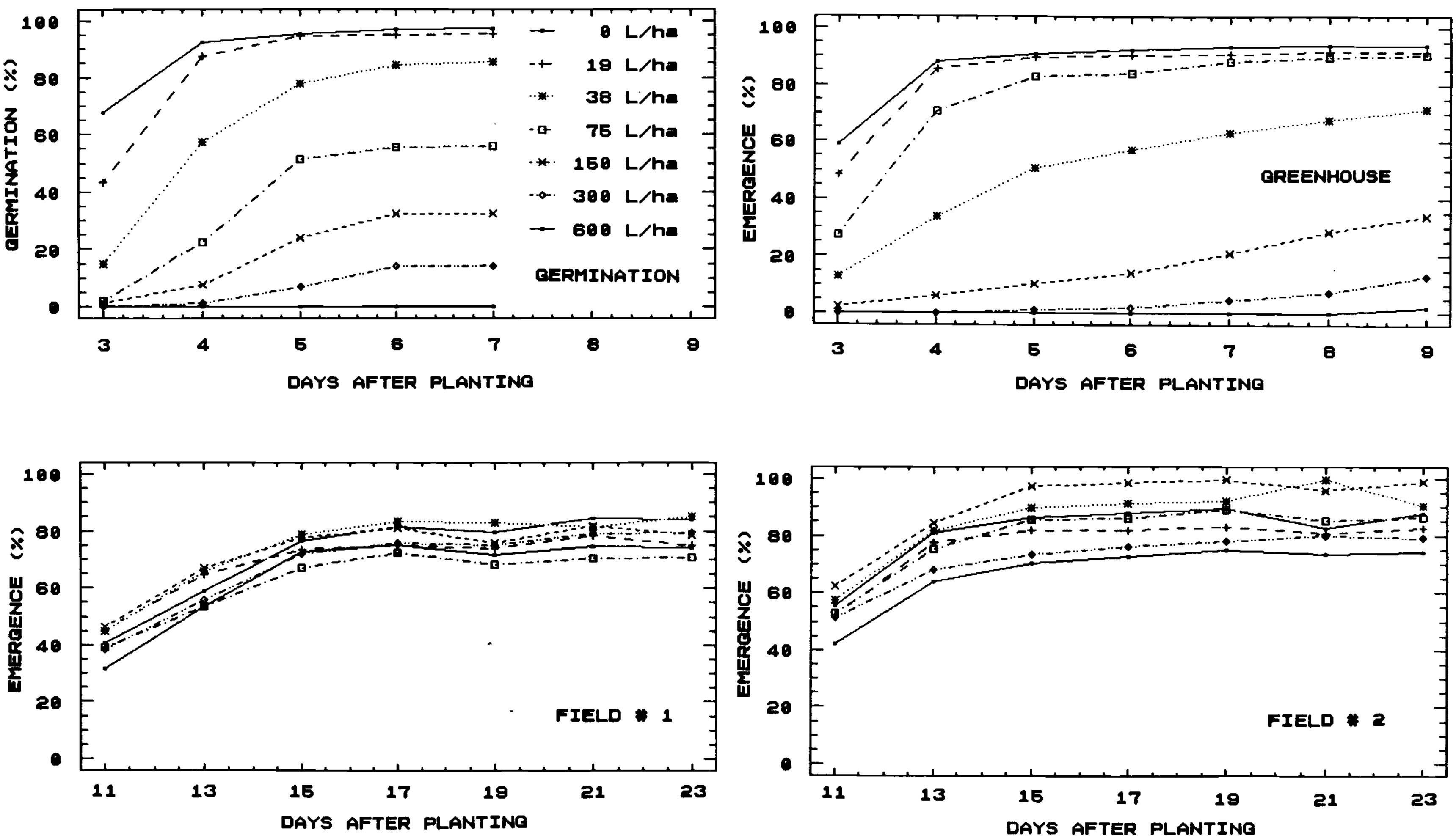
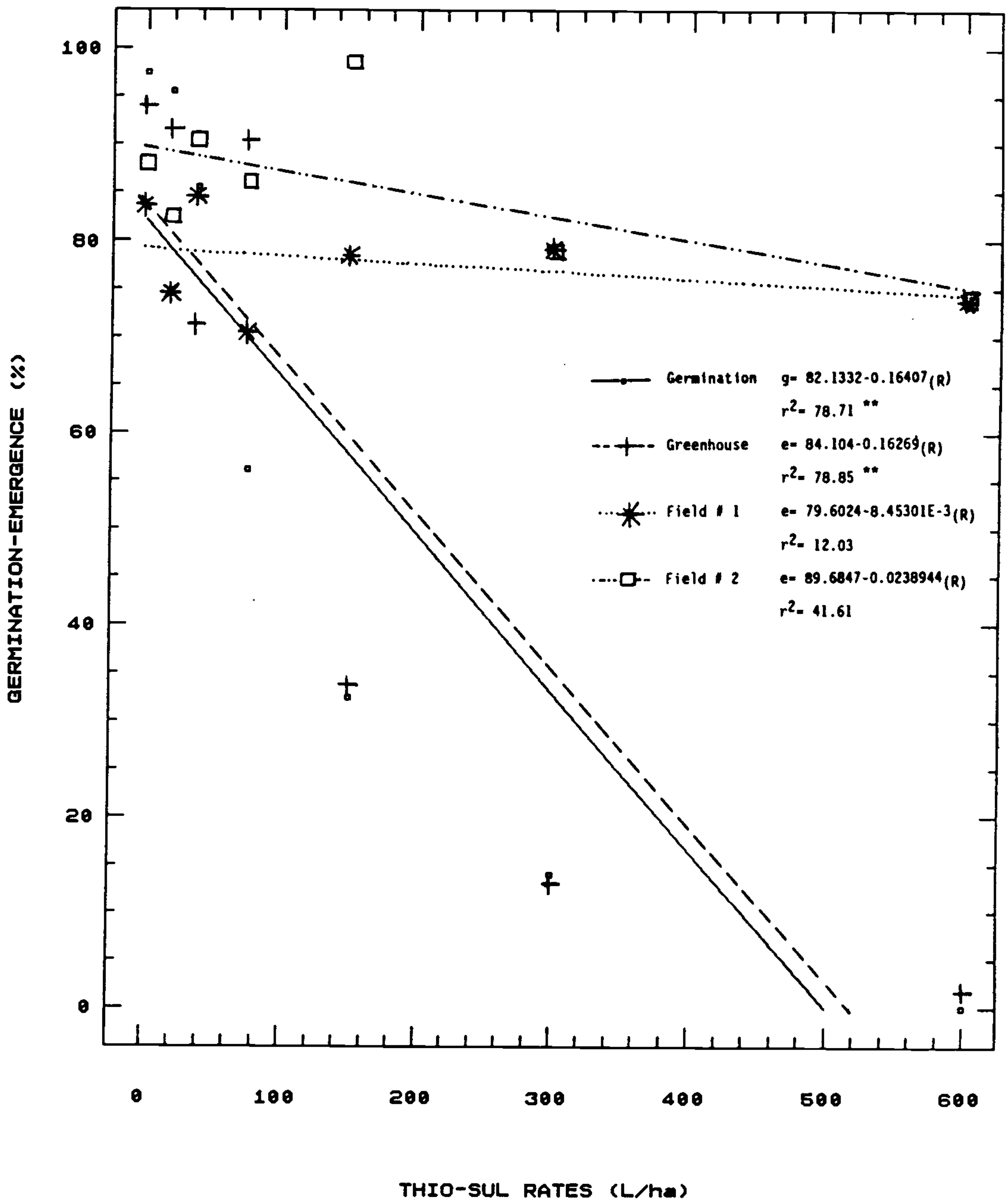


Figure 9. Regression of germination on Thio-Sul rates.



POTASH SOLUTION EXPERIMENTS

The statistical results are summarized in the analysis of variance table for total germination, ERI, and seedling dry weight for each environment studied (Table 18). Two definite patterns were present in the analysis of the results: 1) Highly significant differences were found for all the variables studied in germination and greenhouse experiments, and 2) nonsignificant differences were found for all variables in both field 1 and field 2 experiments.

Germination did not occur at 10 and 15 percent concentration levels, the two highest rates tested in laboratory experiments (Table 19), as compared with results obtained in preliminary experiments where these levels registered 9.33 and 86.00 % of affected germinated seeds in both treatments.

These results show that the liquid Potash solution seems to be very well tolerated in germinating wheat seeds in direct applications at high concentrations. Rates of 300, 600, 1800, and 1800 L ha^{-1} of product in germination, greenhouse, field 1, and field 2 experiments, respectively, had equal response with the check treatment for total germination.

Rates of 75, 300, 1800, and 1800 L ha^{-1} of Potash solution were comparable to the check for ERI at the same order of environments (Table 19).

Seedling dry weight in germination experiments was very sensitive to Potash concentration. Only the seedling dry weight at 75 L ha^{-1} had a similar response with the check treatment. All other treatments containing higher Potash solution levels showed significant differences (Table 20). In greenhouse experiments the higher potassium level and

Table 18. Analysis of variance for total emergence, ERI, and seedling dry weight for Potash solution source.

Environ-ment	Source of variation	df	PR F			
			Total Germin.	Emergence Rate Index	Dry wt. 10 days	Dry wt. 20 days
GERMINATION						
	Total	27				
	Replicat.	3	NS	NS	NS	--
	Rates	6	**	**	**	--
	Error	18				
	C.V.		7.31	13.37	19.17	--
GREENHOUSE						
	Total	27				
	Replicat.	3	NS	NS	NS	NS
	Rates	6	**	**	**	**
	Error	18				
	C.V.		14.77	16.24	14.60	21.00
FIELD # 1						
	Total	27				
	Replicat.	3	NS	NS	NS	NS
	Rates	6	NS	NS	NS	NS
	Error	18				
	C.V.		18.01	20.17	13.93	23.90
FIELD # 2						
	Total	27				
	Replicat.	3	NS	NS	NS	*
	Rates	6	NS	NS	NS	NS
	Error	18				
	C.V.		16.10	15.65	12.40	18.32

**, *, @ -- significant at 0.01, 0.05, and 0.10 probability levels, respectively.
NS -- nonsignificant.
C.V. -- Coefficient of Variation (%)

Table 19. Means for total germination and ERI for Potash solution source.

Solution Concent. (%)	Product L ha^{-1}	Total Germination (%)				Emergence Rate Index			
		Germin.	Greenhouse	Field 1	Field 2	Germin.	Greenhouse	Field 1	Field 2
0.00	0	98.50 a*	84.53 ab	92.57 a	88.03 a	28.15 ab	22.16 a	8.36 a	8.01 a
0.63	75	98.00 a	88.70 a	75.60 a	90.13 a	28.52 a	22.14 a	7.28 a	7.84 a
1.25	150	95.00 a	84.50 ab	77.00 a	93.10 a	23.20 bc	22.33 ab	6.54 a	8.44 a
2.50	300	89.00 a	83.32 ab	74.55 a	94.15 a	22.25 c	21.27 ab	7.01 a	8.53 a
5.00	600	57.50 b	64.88 ab	73.50 a	85.22 a	10.68 d	15.32 bc	7.57 a	7.57 a
10.00	1200	0.00 c	61.90 bc	76.30 a	84.70 a	0.00 e	13.32 cd	7.20 a	7.57 a
15.00	1800	0.00. c	38.10 c	76.65 a	84.88 a	0.00 e	7.17 d	6.58 a	7.60 a

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

Table 20. Means for seedling dry weight (mg) for Potash solution source.

Solution Concent. (%)	Product $L\ ha^{-1}$	Germination	Greenhouse		Field 1		Field 2	
		10 days	10 days	20 days	10 days	20 days	10 days	20 days
0.00	0	5.84 ab*	13.59 bc	32.11 b	16.74 a	51.41 a	9.67 a	17.37 a
0.63	75	6.82 a	15.22 abc	33.81 b	16.40 a	54.46 a	9.53 a	18.06 a
1.25	150	3.89 c	15.65 abc	52.23 ab	16.90 a	58.53 a	9.62 a	16.79 a
2.50	300	4.61 bc	19.44 a	58.52 a	17.21 a	57.40 a	9.20 a	20.06 a
5.00	600	1.84 d	17.30 ab	58.22 a	16.23 a	53.66 a	8.47 a	21.40 a
10.00	1200	0.00 e	15.09 abc	52.88 ab	16.77 a	55.90 a	10.36 a	19.52 a
15.00	1800	0.00 e	11.91 c	53.88 ab	17.50 a	56.43 a	8.43 a	16.15 a

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

the check treatment showed a lower seedling dry weight at 10 days sampling, while at 20 days sampling all the treatments containing more than 150 L ha^{-1} of product had a better response than the check and lower potassium treatments. No differences among treatment levels was found for 10 or 20 days seedling dry weight at both field 1 and field 2 experiments.

Figure 10 presents the percentage of germinated-emerged plants for all the environments studied and for the rate of Potash solution and time of sampling. Clear differences, as those found on the analysis of variance, can be observed when plotting the time of sampling against the germination-emergence percentages. Germination and greenhouse experiments show markedly different total germination percentages among treatment levels, but the differences disappeared in both field 1 and field 2 experiments.

Regression analysis of germination on Potash solution rates and linear model for the environments studied are presented on Fig. 11. Significant differences are found only in germination and greenhouse experiments.

Figure 10. Percentage of germinated-emerged wheat plants as affected by rate of Potash solution liquid fertilizer source and time for germination, greenhouse and field experiments.

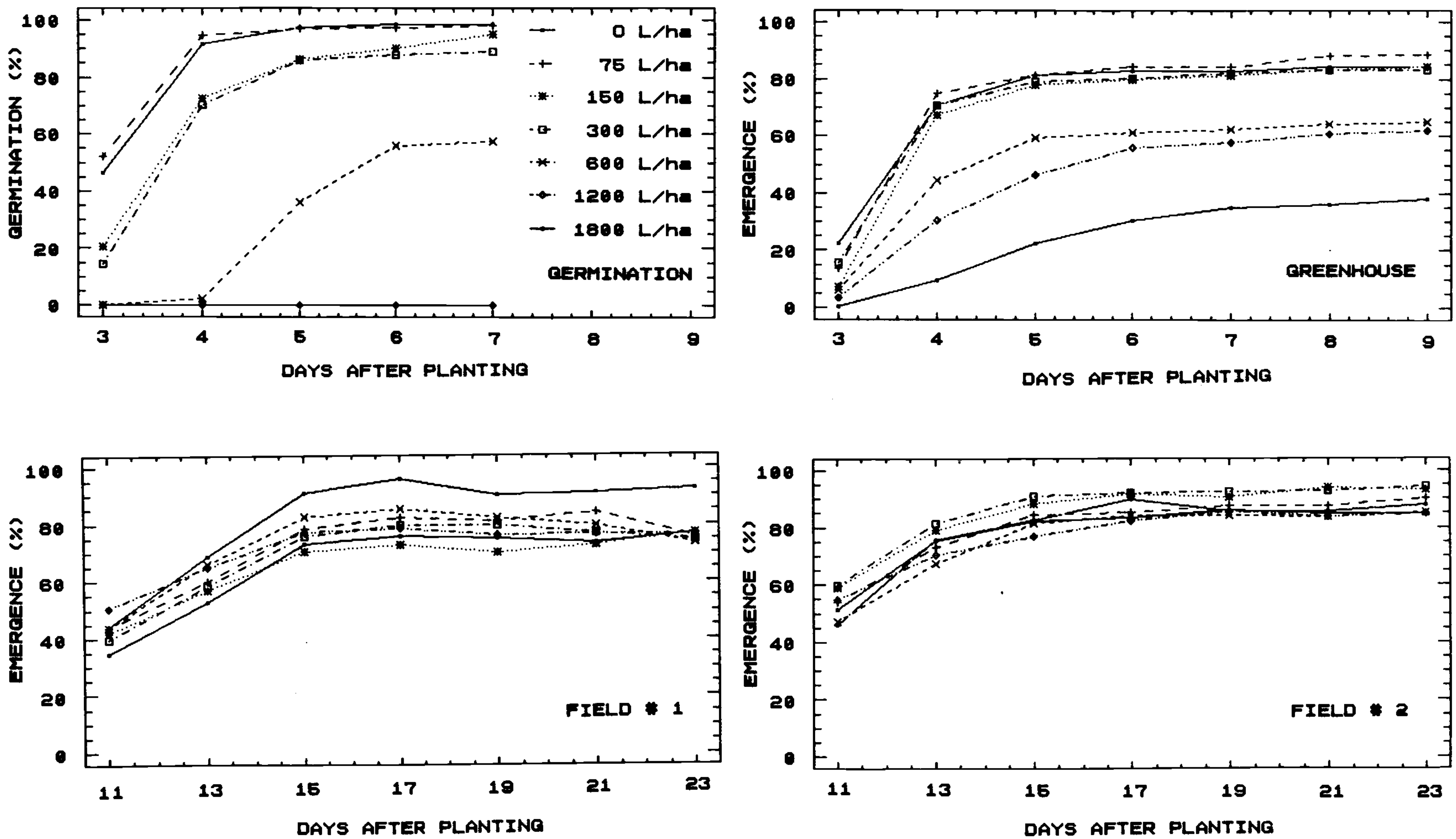
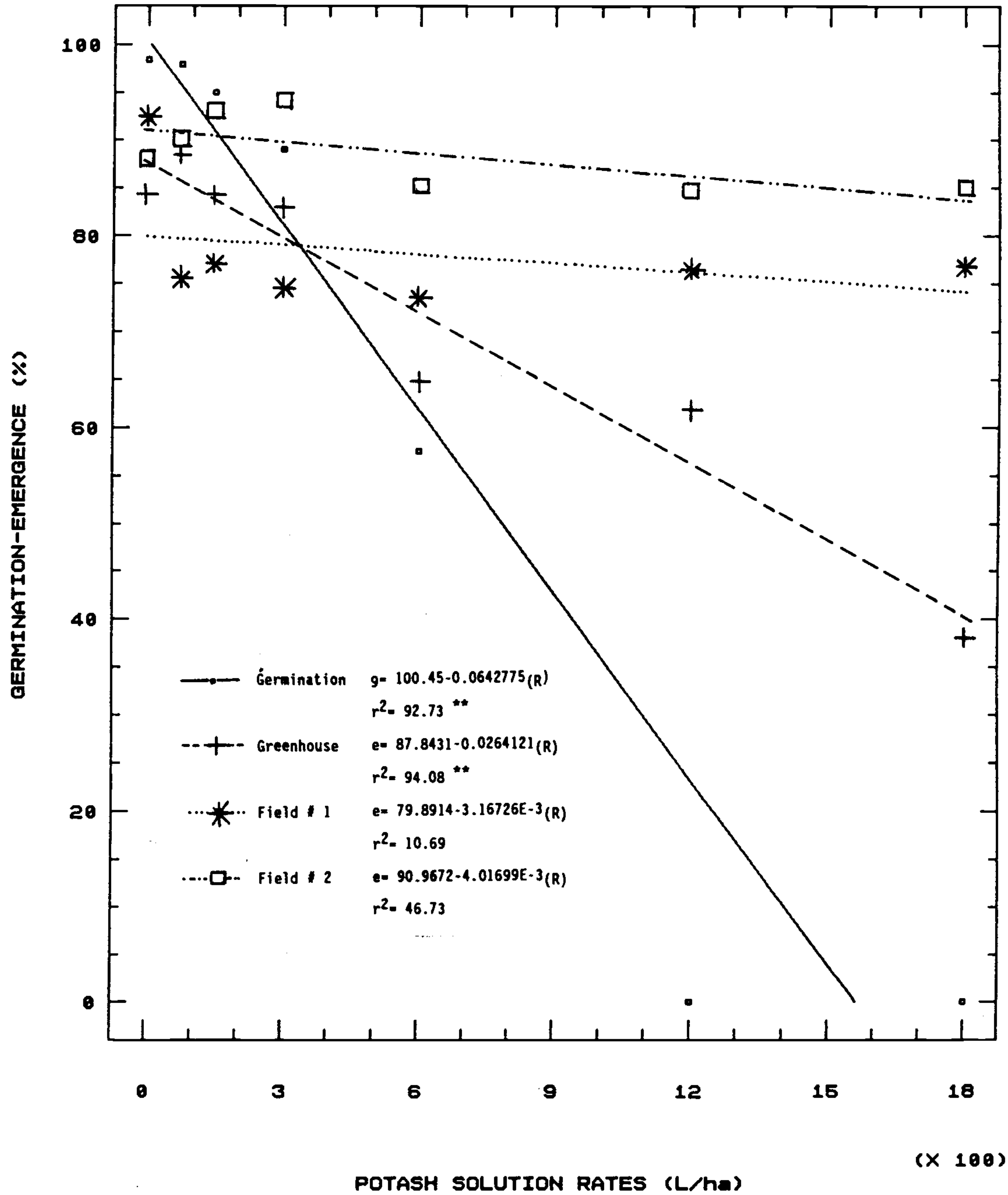


Figure 11. Regression of germination on Potash solution rates.



FEAST 9-18-9 EXPERIMENTS

As a readily commercial available liquid fertilizer mix, Feast 9-18-9 is recommended for small grains at rates of 35 to 45 L ha^{-1} (4-5 gallons per acre) of product at planting for in-row application. The treatments selected to measure effects on total emergence, ERI, and seedling dry weight are presented in Table 21. These selected doses involve levels from 10 L ha^{-1} or one quarter of the recommended dose, to 160 L ha^{-1}, which is four times the recommended dose for starter applications.

Table 21. Concentration, Product, and Rates of N, P, and K for the Feast (9-18-9) experiments.

Concentration (%)	Product (L ha^{-1})	Rate of Nutrients (kg ha^{-1}) N	P	K
0.00	0	0.00	0.00	0.00
0.08	10	1.28	2.56	1.28
0.17	20	2.56	5.12	2.56
0.25	30	3.84	7.66	3.84
0.33	40	5.12	10.23	5.12
0.67	80	10.23	20.47	10.23
1.33	160	20.47	40.94	20.47

The analysis of variance for Feast 9-18-9 concentration levels are presented in Table 22. Highly significant differences were found for all the variables in the germination experiments. The means separation test showed that concentrations up to 0.67 % (application of

Table 22. Analysis of variance for total emergence, ERI, and seedling dry weight for Feast (9-18-9) source.

Environ-ment	Source of variation	df	PR F Total Germin.	Emergence Rate Index	Dry wt. 10 days	Dry wt. 20 days
GERMINATION						
	Total	27				
	Replicat.	3	NS	NS	NS	--
	Rates	6	**	**	**	--
	Error	18				
	C.V.		11.65	16.37	20.98	--
GREENHOUSE						
	Total	27				
	Replicat.	3	NS	@	**	**
	Rates	6	NS	NS	*	**
	Error	18				
	C.V.		4.61	7.50	14.57	13.19
FIELD # 1						
	Total	27				
	Replicat.	3	NS	NS	NS	NS
	Rates	6	NS	NS	NS	NS
	Error	18				
	C.V.		19.68	22.98	12.12	27.64
FIELD # 2						
	Total	27				
	Replicat.	3	*	*	**	*
	Rates	6	*	@	NS	NS
	Error	18				
	C.V.		10.83	10.50	7.48	13.82

**, *, @ -- significant at 0.01, 0.05, and 0.10 probability levels, respectively.
NS -- nonsignificant.
C.V. -- Coefficient of Variation (%)

80 L ha^{-1} of product), have same total germination and ERI as the check treatment without fertilizer application (Table 23). Seedling dry weight showed the same response, except for the treatment with 40 L ha^{-1} of product which had lower seedling dry weight than the treatment with 80 L ha^{-1}.

Nonsignificant responses were found in greenhouse experiments at the Feast levels for germination and ERI (Table 23). Seedling dry weight at 10 days was lower for the check treatment when compared with the fertilizer treatments. These differences were larger at 20 days where treatments containing more than 80 L ha^{-1} had a higher seedling dry weight than the lower Feast rates and the check treatment without fertilizer (Table 24).

Field experiment 1 had nonsignificant response for all the variables studied (Tables 23 and 24). Under the conditions presented for the field 1 experiment, 160 L ha^{-1} of product did not affect significatively any of the parameters studied. The prevalent environmental and physical conditions in field experiment 1 may have been greater than any of the variables in the experiment. The overall total emergence was low, with the check treatment averaging only 77.70 % (Table 23).

In the field experiment 2 the highest rates of Feast were significatively different for total emergence and ERI (Table 23), indicating that applications up to 80 L ha^{-1} of product do not adversely affect these variables. There were no significant differences for seedling dry weight at the concentration levels studied (Table 24). Under the condition prevalent for field experiment 2, doses of 160 L ha^{-1} of Feast did not adversely affect seedling dry weight of wheat at

Table 23. Means for total germination and ERI for Feast (9-18-9) source.

Solution Concent. (%)	Product L ha^{-1}	Total Germination (%)				Emergence Rate Index			
		Germin.	Greenhouse	Field 1	Field 2	Germin.	Greenhouse	Field 1	Field 2
0.00	0	95.50 a*	93.45 a	77.70 a	88.38 ab	26.81 a	22.25 a	6.70 a	8.26 ab
0.08	10	97.50 a	95.22 a	66.50 a	85.05 ab	28.46 a	22.57 a	5.78 a	7.85 ab
0.17	20	97.00 a	95.82 a	71.93 a	90.30 ab	28.82 a	23.78 a	6.22 a	8.32 ab
0.25	30	97.00 a	94.65 a	80.32 a	84.70 ab	23.63 a	23.38 a	7.10 a	8.09 ab
0.33	40	86.50 ab	95.85 a	82.60 a	99.22 a	21.97 ab	23.87 a	7.59 a	8.87 a
0.67	80	95.50 a	94.65 a	74.55 a	80.32 ab	25.83 a	23.91 a	6.62 a	7.55 ab
1.33	160	63.00 b	94.65 a	68.60 a	72.10 b	13.44 b	23.14 a	6.19 a	6.80 b

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HS) Test.

Table 24. Means for seedling dry weight (mg) for Feast (9-18-9) source.

Solution Concent. (%)	Product L ha^{-1}	Germination	Greenhouse		Field 1		Field 2	
		10 days	10 days	20 days	10 days	20 days	10 days	20 days
0.00	0	4.23 ab*	10.64 b	29.48 c	16.26 a	57.83 a	8.75 a	19.22 a
0.08	10	4.75 ab	11.72 ab	31.49 c	17.70 a	66.24 a	8.57 a	17.42 a
0.17	20	5.43 a	13.41 ab	35.38 c	15.55 a	63.87 a	8.07 a	18.84 a
0.25	30	3.73 abc	13.70 ab	33.71 c	17.85 a	63.78 a	8.71 a	17.89 a
0.33	40	3.35 bc	12.84 ab	40.11 bc	18.97 a	63.95 a	8.12 a	17.89 a
0.67	80	3.53 abc	16.01 a	51.17 ab	17.55 a	65.96 a	7.51 a	20.44 a
1.33	160	2.25 c	14.63 ab	57.12 a	16.43 a	63.51 a	8.49 a	16.08 a

* Within each column, means not followed by a common letter are significantly different (5 % level) using Tukey's (HSD) Test.

10 and 20 days after first emergence.

Figure 12 presents the percentage of germinated-emerged plants in the environments for the Feast liquid fertilizer rates and date of sampling. Only germination and field 2 experiments show some differences among the treatment data plotted.

The regression analysis and linear model for the environments studied is presented in Fig. 13. Only the data from the germination experiment appears to have any practical importance.

Figure 12. Percentage of germinated-emerged wheat plants as affected by rate of Feast (9-18-9) liquid fertilizer source and time for germination, greenhouse and field experiments.

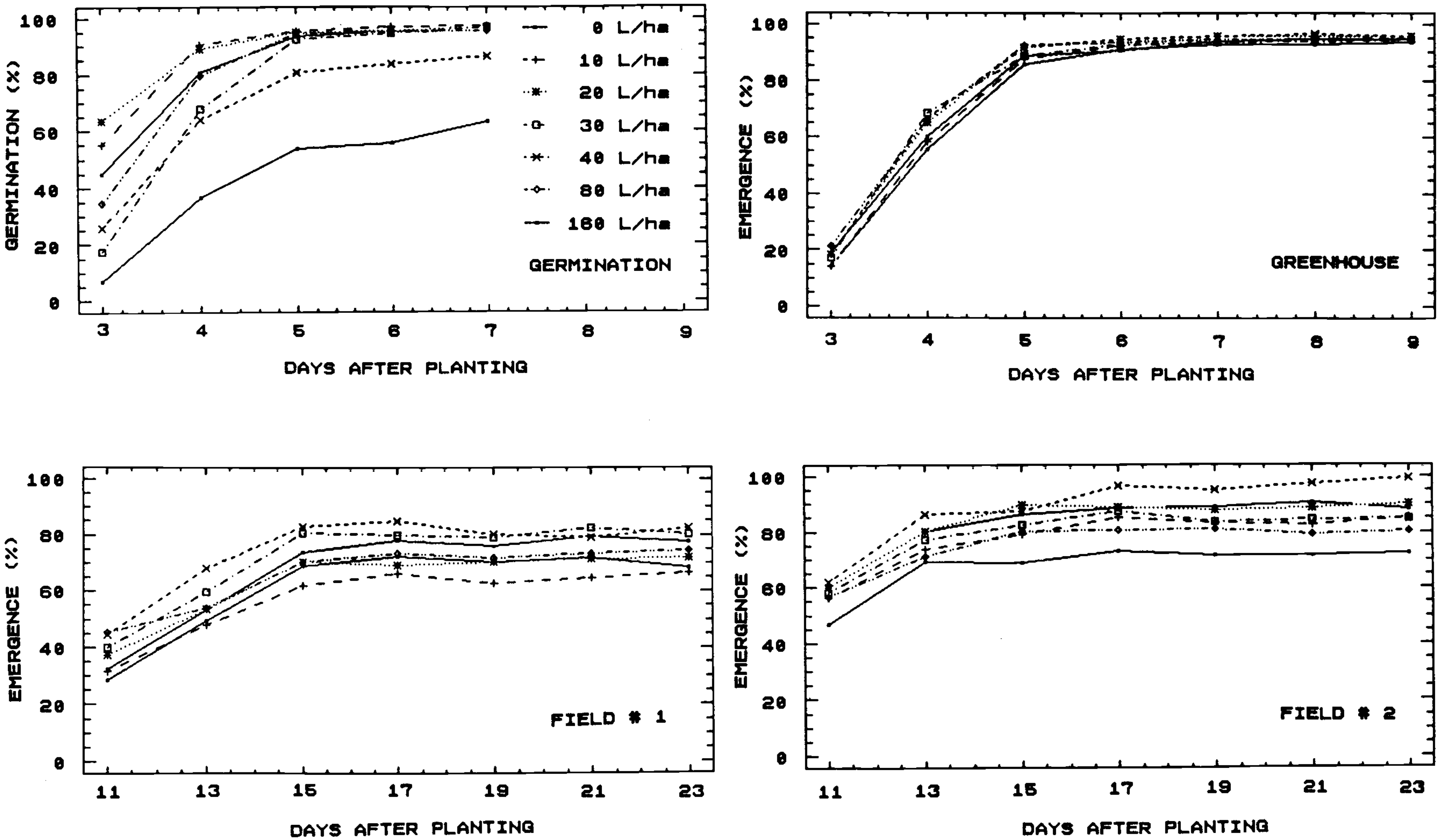
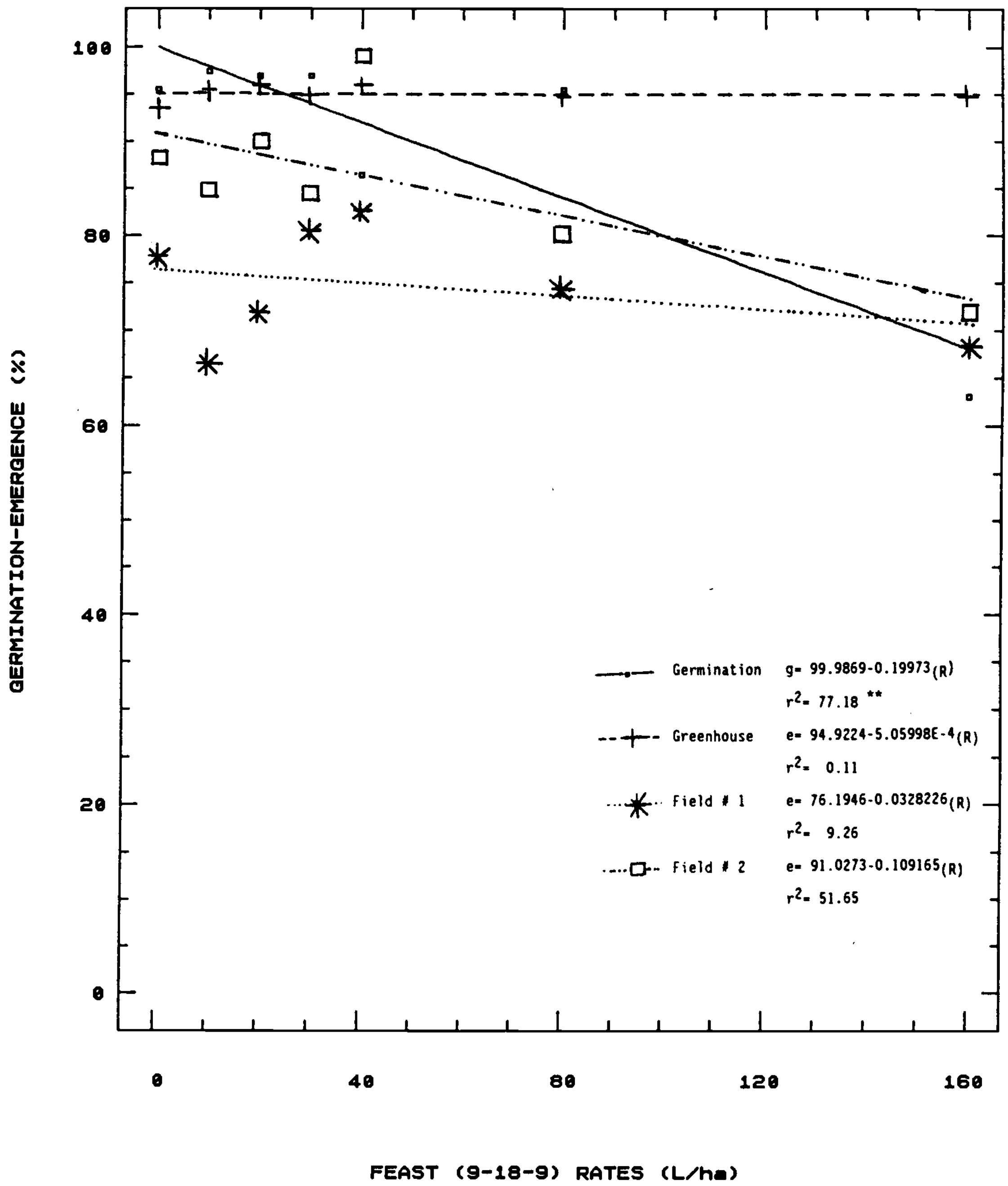


Figure 13. Regression of germination on Feast (9-18-9) rates.



SUMMARY AND CONCLUSIONS

The objectives of these studies were to determine the level of concentration at which some selected liquid fertilizers would significantly affect the germination, emergence rate index, and seedling dry weight of wheat when directly applied to the seed.

Four basic liquid fertilizers: Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, and one commercial liquid fertilizer, Feast (9-18-9), were utilized in these studies.

Preliminary experiments using the basic materials, in laboratory germination tests, showed three distinct concentration levels for each source: 1) lethal dose, where no signs of germination were present; 2) critical dose, where concentration levels showed delay or detrimental effects on germination; and 3) safe dose, where seeds produced normal seedlings.

In the germination experiments, the lethal concentrations were at 4, 5, 5, and 15 % solution concentration for Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, respectively. The critical concentration was identified at 0.25, 0.08, 0.08, and 3 % solution concentration for the same materials.

Preliminary experiments indicated that 80 % germination could be obtained at rates of 143.5, 205.28, 91.85, and 576.17 L ha^{-1} of product for Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, respectively. Simple regression analysis indicated that as the rate of liquid fertilizer source increased, total germination decreased in a linear manner. For each 10 L ha^{-1} of product applied, germination decreased in 1.52, 0.86, 0.89, and 0.40 % for Solution 32, 10-34-0-.9, Thio-Sul, and Potash solution, respectively.

Germination, greenhouse, and two field experiments were conducted with the five liquid fertilizer sources to evaluate the concentration levels on germination, emergence rate index, and seedling dry weight.

Solution 32 concentrations from 90, 240, 480, and 240 L ha^{-1} were comparable on total germination and ERI to the treatment without fertilizer for germination, greenhouse, field experiment 1, and field experiment 2, respectively. Seedling dry weight showed a similar response, except at 20 days in greenhouse experiment, the check treatment had lower seedling dry weight than the treatments up to 240 L ha^{-1} of product.

Wheat seeds tolerated 10-34-0-.9 at higher rates than Solution 32. Ranges up to 75, 300, 600, and 600 L ha^{-1} were comparable to the check treatment without fertilizer for total germination for the germination, greenhouse, field experiment 1, and field experiment 2, respectively. ERI was comparable to the check treatment at ranges up to 38, 150, 600, and 600 L ha^{-1} for the same order of environments. Seedling dry weight was highly sensitive only in germination experiments, and was not significantly different when the soil was growth medium for the seeds.

Total germination and ERI showed a similar response to the check treatment for Thio-Sul concentrations from 19, 75, 600, and 600 L ha^{-1} of product for germination, greenhouse, field experiment 1, and field experiment 2, respectively. Seedling dry weight responded significantly in the germination and greenhouse experiment, while in the field experiments seedling dry weight was the same for all the treatments with the exception of 10 day seedling dry weight in field experiment 1.

Among the sources studied, Potash solution was the one tolerated at higher solution concentrations by the seed. Rates of 300, 600, 1800, and 1800 L ha^{-1} of the product had equal response with the check treatment for total germination in germination, greenhouse, field 1, and field 2 experiments, respectively. Rates of 75, 300, 1800, and 1800 L ha^{-1} of Potash solution were comparable to the check for ERI in the same environments. Seedling dry weight appears to be very sensitive in germination and greenhouse experiments, but no differences among treatment levels was found at both field 1 and field 2 experiments.

Feast (9-18-9) rates studied were at lower concentration levels than the basic materials. Rates up to 80, 160, 160, and 80 L ha^{-1} had similar response to the treatment without fertilization for total germination and ERI variables in germination, greenhouse, field 1, and field 2 experiments, respectively. Seedling dry weight was affected at doses higher than 80 L ha^{-1} in germination experiments. In greenhouse experiments the addition of fertilizer had a positive response on seedling dry weight, especially at 20 days where doses of 80 and 160 L ha^{-1} of product significantly increased seedling dry weight.

The technique developed in this study appears to be a quick and efficient method to screen for liquid fertilizer toxicity. The laboratory and greenhouse technique allows for more controlled conditions than in field studies. Under field conditions a greater range of treatments would be required. In this study, the fertilizer concentrations selected were on the basis of laboratory results, which when translated to field situations, generally did not show significant differences in delayed germination or reduced seedling growth.

Among the basic liquid fertilizers studied, Thio-Sul showed greater toxicity, on a L ha^{-1} basis, to germinating wheat seeds in germination and greenhouse experiments.

Solution 32 and 10-34-0-.9 liquid fertilizer sources showed a similar and intermediate response in toxicity. The differences were not detected under the prevalent field conditions.

Potash solution was tolerated at much higher concentration. It appears that this material in a customized solution mixture, at the normal rates of K applied, will not negatively interact with the other nutrients in delaying or affecting wheat germination.

The commercial liquid fertilizer studied, Feast (9-18-9), showed no detrimental effect at the recommended rates for wheat. In the germination experiments, twice the recommended concentration was comparable with the treatment with no fertilization. In greenhouse and field experiments, up to four times the recommended rates performed similarity to the check treatment.

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