PHYSICAL AND CHEMICAL COMPATIBILITY OF HERBICIDE-SUSPENSION FERTILIZER COMBINATIONS

by

LOUIS JON MEYER

B.S., Kansas State University, 1970

42-6074

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

Approved by:

Larry Murphy
Major Professor

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Sincere appreciation is expressed to Dr. Larry Murphy, major professor, and to Professor Oliver Russ for their advice and counseling during the course of study. Their assistance in designing the studies, performing the research, and preparing the manuscript is also appreciated. Thanks is also extended to Dr. John Schafer who served as a member of the supervisory committee.

Special appreciation is expressed to the Test and Demonstration Branch of the Tennessee Valley Authority for their financial and material assistance, and to Allied Chemical Corporation for the nitrogen solutions used in the investigations.

Appreciation is extended to Dr. Richard Vanderlip for advice and counseling on statistical procedures, to Dr. David Whitney for advice and counseling on chemical procedures, and to members of Kansas State University's Soil Fertility and Weed Science staffs who provided assistance with plot work and chemical analysis.

Special appreciation is expressed to the author's wife, Cathy, for her sacrifices, encouragement, and understanding during the course of study, and to the author's families, Mr. and Mrs. Louis Meyer, Jr., and Mr. and Mrs. Glenn Allison for their support and interest in the work.

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

INTRODUCTION

The practice of applying pesticides in fluid fertilizers has developed with the recognized necessity of cutting food production costs. Combining fertilizer and pesticide applications has the obvious advantages of reducing equipment, labor, and time requirements.

One of the primary considerations when applying pesticide-fertilizer combinations is optimum timing and placement of the mixture. To obtain maximum benefits from a combined application, the proper time and method of application for the fertilizer and pesticide must coincide. On field crops, optimum herbicide application methods correspond with optimum fertilizer application methods more often than do insecticide applications. Insecticides are frequently not applied until their need is recognized, and this is usually too late to apply fertilizer economically. Herbicides are used extensively on field crops prior to plant growth - timing which corresponds well to most applications of fertilizer.

Another primary consideration is the feasibility of manufactured or dealer-formulated mixtures of herbicides and fertilizers. Before such a practice can be effective, it must be established that the combined materials will remain functional after being stored in contact for extended periods of time.

Simultaneous applications of fertilizer-herbicide mixtures are currently used primarily on corn (*Zea mays* L.), with about

10% of corn herbicides being applied in combination with fluid fertilizer (Murphy, 1971). One of the biggest limitations in the use of liquid fertilizer-herbicide mixtures has been the lack of agronomic research information (Furtick, 1968). Because suspension fertilizers were developed much later than true solution fertilizers, less is known about their compatibility with herbicides.

Visual observation will indicate whether fertilizer and herbicide materials will mix sufficiently for application. However, this physical compatibility tells nothing about chemical compatibility, particularly with suspension fertilizers. Due to the presence of colloidal materials in suspension fertilizers, a herbicide will most likely be held in the fluid with no adverse effects. Even though a herbicide may remain in suspension, an alteration of the combined materials may occur causing them to become ineffective. Adsorption of herbicide molecules by the negatively charged clay particles present in suspension fertilizers is one possibility.

Based on the need for more information concerning simultaneous applications of fertilizers and herbicides, investigations were initiated at Kansas State University to determine the compatibility of some common field crop herbicides and suspension fertilizers. Studies were also designed to evaluate different application methods and the effect of extended fertilizer-herbicide contact times on the activity of the herbicide formulations.

REVIEW OF LITERATURE

History

The concept of combining fertilizers and pesticides for simultaneous applications is not a new one but only a limited amount of research has been conducted on the effectiveness of such mixtures. Jacob (1954) reported that in the year ending June 30, 1953, fertilizer-pesticide mixture consumption totaled 87,000 tons for the United States and Territories. This amounted to only 0.55% of the total mixed fertilizer consumption. Jacob found these early combinations were primarily mixtures of solid materials. Most of the emphasis was on fertilizer-insecticide mixtures, while fertilizer-herbicide mixtures were largely limited to the use of 2,4-dichlorophenoxyacetic acid (2,4-D) in solid fertilizers. Problems were encountered in obtaining uniform fertilizer-pesticide mixtures using dry materials, and bulk sale of the mixtures was not permitted in a number of states. Also, the commercialization of fertilizer-pesticide mixtures had outrun the research in the area. The result was much diversity of opinion as to their merit and practical feasibility.

The work of Jacob is supported by Murphy (1971) who reported that use of fertilizer-pesticide combinations started in earnest about 1954 with the introduction of soil insecticides, especially the chlorinated hydrocarbons. He noted that early combinations of herbicides with fertilizers entailed direct impregnation of solid fertilizers with some of the liquid herbicide formulations.

Early emphasis on liquid fertilizer-herbicide mixtures was an attempt to improve the weed control characteristics of some of the chemicals (Furtick, 1968). This was particularly characterized by the use of 2,4-D, because the adhesive properties of liquid fertilizer on plant foliage would substantially increase the effectiveness of 2,4-D - liquid fertilizer mixtures. Also, the heavier fertilizer solutions were subject to less wind drift.

Herbicide-Phosphorus Interactions

Several research reports have dealt with the effect of plant nutrients on herbicide activity and the effect of herbicides on plant nutrient uptake. Much of this research did not deal with simultaneous applications of the materials, but because interactions which occur without simultaneous applications raise the possibility of similar or increased effects using a dual application, these interactions will be reviewed. No reported research is available describing the effectiveness of herbicide-suspension fertilizer mixtures.

Herbicidal effects on phosphorus nutrition have been noted. Loustalot et al. (1953) showed that application of 2,4-D to white bean plants increased the inorganic P content in the plant. Using cranberry beans (*Phaseolus vulgaris*), this increase was later shown to be due to accumulation of P in the stems of plants (Rebstock, Hamner, and Sell, 1954). However, Wildon, Hamner, and Bass (1957) reported opposite results. Their studies showed 2,4-D treated tobacco plants (*Nicotiana tobacum* L.) contained a smaller phosphorus percentage in the plant tops than did untreated plants.

DeVries (1963) noted that 2-chloro-4,6-bis(ethylamino)-*s*-triazine (simazine) significantly increased the uptake of phosphorus on limed soils by corn and Monterey pine (*Pinus radiata*). Dhillon, Byrnes, and Merritt (1967) found that phosphorus uptake was stimulated by simazine levels of 5 and 10 ppmw, but was inhibited at higher levels of 15 and 20 ppmw in red pine seedlings (*Pinus resinosa* Ait.).

Sabbe (1967) reported *a*,*a*,*a*,trifluoro-2,6-dinitro-*N*,*N* dipropyl-*P*-toluidine (trifluralin) decreased phosphorus uptake in the zone of the herbicide on soybeans (*Glycine max* (L.) Merr.) and cotton (*Gossypium hirsutam* L.). However, this decrease was partially modified by increasing the phosphorus uptake from zones other than the herbicide zone. Uptake of phosphorus was greater when it was applied separately from the herbicide, but highest when the herbicide was omitted. These results suggested broadcast applications of phosphorus and trifluralin in the same zone should be discouraged.

The results of greenhouse studies (Mortvedt, Sample, and Giordano, 1969) revealed a decrease in phosphorus uptake by cotton when trifluralin and 4-(methyl-sulfonyl)-2,6-dinitro-*N*,*N*-dipropylaniline (Planavin) were banded with phosphorus-containing liquid fertilizers. Their results agree with those of Sabbe, but simultaneous broadcast applications of the same fertilizer-herbicide formulations did not affect phosphorus uptake. Using the same liquid fertilizer carriers, 2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine (atrazine) was applied to corn. Phosphorus uptake of corn was not affected by incorporation of atrazine with the various fluid fertilizers (Mortvedt et al., 1969).

The effect of phosphorus on herbicide activity has been observed by some researchers. Studies on cotton and Italian ryegrass (Lolium multiflorum L.) showed that the addition of phosphorus increased plant growth in the absence of 3-(3,4-dichlorophenyl)-1,1-dimethyl urea (diuron), but caused little or no response for plants grown in the presence of intermediate diuron rates (Bingham and Upchurch, 1959). They postulated that phosphorus and diuron interact, and the affect of diuron on plant growth is partially regulated by the phosphorus level.

High levels of soil phosphorus displayed increased toxicity of 3-amino-s-triazole (amitrole) to cotton when compared to low levels of soil phosphorus (Upchurch, Ledbetter, and Selman, 1963). Vega (1964) found that phosphorus can, depending upon its concentration and length of exposure to the phosphate-amitrole treatment, enhance uptake and/or translocation of amitrole-^{14}C. This influence was thought to be effected through the formation of a complex. An optimum phosphate concentration was noted which caused maximum enhancement of amitrole phytotoxicity.

Selman and Upchurch (1970) studied the influence of soil-applied phosphorus on the phytotoxicity of amitrole and diuron for corn, ryegrass, rye (*Secale cerale* L.), snapbeans (*Phaseolus vulgaris* L.), soybeans, sorghum (*Sorghum vulgare* Pers.), wheat (*Triticum aestivum* L.), peanuts (*Arachis hypogaea* L.), peas (*Pisum sativum* L.), and cotton under greenhouse conditions. All species except cotton and peanuts indicated an amitrole-phosphorus interaction. Greater phytotoxicity was observed at a given rate of amitrole as the soil phosphorus level increased.

In greenhouse studies conducted by Adams (1965) high levels of phosphorus tended to suppress growth of soybeans, oats (*Avena sativa* L.), and foxtail (*Setaria faberri* Herrm.) in the presence of simazine.

Doll, Penner, and Meggitt (1970) reported atrazine and 3-amino-2,5-dichlorobenzoic acid (Amiben) phytotoxicity was enhanced in the presence of high phosphate levels on corn and squash (*Cucurbita maxima* Duchesne) seedlings. This effect was not due to increased uptake of either herbicide, but rather a phosphate effect on herbicide activity.

Herbicide-Nitrogen Interactions

Herbicides were first observed to have an affect on nitrogen uptake and metabolism shortly after the introduction of 2,4-D. Stahler and Whitehead (1950) investigated the KNO_3 level of sugar beet (Beta vulgaris) leaves which had accidentally been sprayed with 2,4-D. They found that nitrate levels were three times the lower toxic limit established for livestock, and concluded the high levels were caused by 2,4-D.

Berg and McElroy (1953) reported significant increases in the nitrate content of Russian pigweed (Amaranthus sp.) and Canada thistle (Cirsium arvense) after treatment with 2,4-D. However, they found no increase in the nitrate content of a number of forage crops and other weedy species after 2,4-D application. Work by Swanson and Shaw (1954) showed the application of 2,4-D to sudan grass grown in the field resulted in a brief increase in nitrates followed by a rapid decrease to levels below the controls. One month after treatment, nitrate content of the treated plants had increased to levels equal to or greater than controls.

In recent years a number of researchers have noted the effect of triazine herbicides on plant nitrogen components. Research conducted by DeVries (1963) showed a significant increase in the uptake of nitrogen by corn when treated with simazine.

Ries, Larson, and Kenworthy (1963) reported peach trees treated with a herbicide mixture of simazine and 3-amino-1,2,4-triazole plus ammonium thiocyanate (amitrol-T) had higher leaf nitrogen content and more growth than did trees where the weeds were controlled by hand hoeing or with a black plastic mulch. Apple trees treated with the same herbicide mixture had higher leaf nitrogen and more growth than those trees with no weed control had.

Later, Ries and Gast (1965) found the addition of simazine to nutrient solutions of corn grown under environmental stress conditions increased the total amount and concentration of N in the plants. Under more favorable conditions only the concentration of N in the shoots was increased, and then only at lower nitrogen levels. Corn plants treated with hydroxysimazine responded similarly to the controls.

Ries et al. (1967) reported simazine applied at subtoxic levels increased the growth and nitrogen content of corn grown with nitrate, but not of corn grown with ammonia as the nitrogen source. These effects were greatest when nitrate and temperature were at suboptimal levels. The same investigations also revealed optimum simazine levels markedly increased the accumulation of protein in rye and pea plants receiving nitrogen as nitrate.

Fink and Fletchall (1967) treated corn with atrazine or simazine plus 32% N liquid fertilizer in the field. Five weeks after planting, the N concentration in corn forage rose sharply due to herbicidal treatments, especially on those plots not treated with nitrogen fertilizer.

In field experiments with corn and Johnson grass (Sorghum halepense), Gramlich and Davis (1967) noted that atrazine treated plants of both species usually were smaller than untreated plants and contained higher nitrogen percentages. However, corn and Johnson grass treated with high rates of atrazine (8ppmw and 4 lb/A respectively) always contained less nitrogen (mg/plant) than untreated plants. The observed increase in N concentration was mainly a result of increased nitrate percentages and not free ammonia increases.

Eastin and Davis (1967) reported that atrazine increased the percent N in a number of plant species studied whether resistant, intermediate, or susceptible to 1 lb/A of atrazine. In these field soil culture and nutrient culture experiments, nitrogen content per plant was either unaffected or decreased by atrazine treatments. The percentage of protein and nitrate nitrogen was generally increased with atrazine applications. One lb/A of 2-hydroxy-4-ethylamino-6-isopropylamino-s-triazine (hydroxyatrazine), a degradation product of atrazine, had no consistent effect on any nitrogen fraction studied.

Corn grown in controlled environment chambers and in the field which was treated with atrazine, displayed an atrazine-induced increase in nitrate nitrogen content only at low temperatures (Doll and Meggitt, 1968). No accumulation of nitrate at the silage stage of treated corn was observed.

Not only have herbicides affected plant nitrogen contents, but nitrogen materials have produced increases in herbicide effectiveness. Minshall (1969) studied the effect of potassium nitrate and urea on the uptake of four triazine herbicides in tomato (Lycopersicum exculentum Mill.) plants. He reported an increased rate of exudation from the stumps of plants treated with either nitrogen form. Regardless of nitrogen form, there was an increase in the concentration of the triazine herbicides in the exudate resulting from nitrogen treatments.

McReynolds and Tweedy (1970) found the shoots of rye, soybean, and corn plants contained more ^{14}C-labeled simazine when grown on nitrate nitrogen than when grown on ammonium nitrogen.

Doll (1969) observed that nitrogen supplied as nitrate increased the phytotoxicity of atrazine, amiben, and 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea (linuron) to oats. A measure of the absorption of these herbicides was conducted using ^{14}C-labeled materials on corn, soybean, and pigweed (*Amaranthus retroflexus* L.). The increased phytotoxicity of these materials with increasing nitrate levels was not a result of greater herbicide absorption.

Brady (1970) found that the addition of ammonium nitrate greatly increased the absorption of 2,4,5-trichlorophenoxy-acetic acid (2,4,5-T) solutions by a variety of tree species. Phosphoric acid alone or mixed with ammonium nitrate caused less increase in absorption.

Other Herbicide-Plant Nutrient Interactions

Cooke (1957) studied the influence of 2,4-D on the uptake of a number of nutrients by bean plants. His results showed that 2,4-D increased the uptake of potassium, chloride, calcium, and sulfur during the first few hours after spraying, but after 48 hours the 2,4-D treatments inhibited the uptake of these nutrients.

Wildon et al. (1957) reported tobacco plant tops treated with 2,4-D contained smaller percentages of potassium and sodium and greater percentages of boron and iron than did the untreated plants. Roots of treated plants accumulated more calcium and less copper than roots of untreated plants. Treatment with 2,4-D caused little or no difference in accumulation of calcium, copper, magnesium, and manganese in roots.

Wort (1962) reported the application of mineral elements in combination with 2,4-D provided not only yield advantages, but also increased fruit and grain qualities. Iron, in particular, applied with the herbicide reduced its phyto-toxicity.

Simazine was reported to increase significantly the up-take of potassium in acidified soils by corn (DeVries, 1963). An increase in Ca and SO_4 uptake from nutrient solutions in juvenile corn, soybeans, and large crabgrass (*Digitaria sanguinalis* (L.) Scop.) was obtained with linuron treatments at various rates (Nashed and Ilnicki, 1968).

Effect of Simultaneous Applications on Yields

Limited research is available on the effects of herbicide-solution fertilizer mixtures on crop yields. Fullilove (1968) reported a combination of 2,4-D and liquid ammonium nitrate significantly lowered corn yields in comparison to single applications of the materials at recommended rates.

Fink and Fletchall (1967) treated corn with 0, 2.5, 5, and 10 lb/A of atrazine or simazine plus 0, 100, or 200 lb/A of 32% N liquid fertilizer in the field. Five weeks after planting, corn forage yields were significantly reduced by all herbicidal treatments. Greater forage yield reductions occurred with simazine treatments than with atrazine treatments. In successive harvests during the same year forage yields were less affected by the treatments than preceding harvests. Grain yields were largely unaffected by herbicidal treatments except when 10 lb/A of simazine was applied. High simazine rates reduced grain yields.

Research by Mortvedt et al. (1969) reported lowered cotton yields when trifluralin and liquid 10-15-0 (10-34-0) fertilizer were applied simultaneously as a banded application, but broadcast applicztions of this mixture did not change yields. Liquid fertilizer-atrazine combinations did not affect corn yields in comparison to fertilizer-only treatments in the same investigation.

Physical Compatibility

Some information is available relative to the physical compatibility of a number of pesticide-fluid fertilizer mixtures. At a recent meeting of the American Chemical Society (ACS), Achorn outlined a simple, four-step procedure for making compatibility tests in the field (Achorn, F.P. and E.B. Wright Jr. Paper presented at Washington, D.C., ACS Meeting - September 13-15, 1971. Division of Agricultural Development. Tennessee Valley Authority, Muscle Shoals, Alabama.):

1. Place a pint of the fertilizer mixture in a quart jar.

2. Add two teaspoonfuls of pesticide.

3. Close jar and shake well.

4. Observe mixture at once and again after 30 minutes.

Achorn noted that this test will quickly show whether the pesticide and fertilizer will mix, and the same test can be made with a compatibility agent by adding one-third teaspoonful of agent in the second step.

Observations were conducted by TVA using this physical compatibility check on 32 pesticides in six fluid fertilizers (three suspensions and three clear liquids). Results indicated all but one pesticide were compatible with all three suspensions. The pesticides were much less compatible in the clear liquid fertilizers giving precipitations or separations. Emulsifying agents were found to help prolong uniform pesticide-fertilizer mixtures.

Furtick (1968) reported that most ester formulations will mix satisfactorily with fluid fertilizers, but that amine formulations will not. Wettable powders in general will readily mix without problems. Furtick recommends a compatibility test similar to TVA's if compatibility is not known. Commercial formulations with lower concentrations of active herbicide will be more satisfactorily dispersed in nitrogen solutions than compounds with higher concentrations of active ingredients (Klosterboer and Bardsley, 1968).

Even when materials are physically compatible, good agitation is required at all times (Achorn, Scott, and Wilbanks, 1970; Furtick, 1968; Murphy, 1971), and long storage periods are not recommended due to lack of research information (Furtick, 1968; Schneider, Moye, and Kincannon, 1969).

Other Considerations

Herbicides which are not labeled for use in fluid fertilizers should not be mixed (Schneider et al., 1969), because liquid fertilizers vary in density, viscosity, and salt concentration. In many cases the liquids are near chemical saturation, and herbicide addition could result in physical and chemical reactions between the materials. This might ultimately affect herbicide performance, even when labeled materials are used.

King (1970) noted that when a herbicide-fertilizer mix is made, the mixture itself becomes a herbicide and should be treated as such. The mixture should be handled as a potentially dangerous herbicide, and all precautions on the herbicide label should be strictly observed.

Petty, Burnside, and Bryant (1971) reported on the legal aspects of herbicide-fertilizer combinations. The Environmental Protection Agency (EPA) currently administers laws which govern registration of pesticides entering interstate commerce, and federal regulations require a label stating how a herbicide can be applied in combination with fertilizer. Without this approved label, the herbicide should not be applied with fluid fertilizers. The herbicide label will include mixing and application procedures for use with fertilizers. These procedures must be followed in dealer and farm tanks.

Applications for registration of a mixture require supporting data leading to conclusions regarding new properties, if any, of the herbicide. In cases where fertilizer-herbicide combinations are to be manufactured as a product, a new label for the mixture, separate from the pesticide label, must be registered and approved by appropriate agencies.

METHODS AND MATERIALS

The effectiveness of plant nutrients (N,P,K) when combined with herbicides was studied two consecutive years in the field and in three growth chamber experiments. Length of fertilizer-herbicide contact and the method of application were included as variables in determining the usefulness of simultaneous application of herbicides and plant nutrients. Physical compatibility determinations were made on all mixtures utilized.

Field Studies Using Atrazine

The experiments utilized a randomized complete block design with three replications. Two locations with different soil types were used in both 1970 and in 1971. Soil test data (surface 15 cm) acquired prior to material application on all locations is presented in Table 1. One location (Manhattan) was situated on a Kahola silt loam, and the Ashland location on a Muri silt loam. In 1971 the Ashland site was moved to facilitate irrigation, but was still situated on a Muri silt loam. The Manhattan location was not moved, the 1971 treatments (comparable) being superimposed on the 1970 treatments. 'Pioneer 321' corn was planted in 76 cm rows. Plot width and length were 3.05 m and 9.15 m respectively. The three dryland studies were planted to a population of 46,950 plants per hectare, the irrigated site to 54,360 plants per hectare.

Table 1. Soil test data for field study sites.

Location	Year	Organic Matter %	Avail. P kg/ha	Exch. K kg/ha	pH
Manhattan	1970	2.6	35	358	6.2
Manhattan	1971	2.6	45	358	6.5
Ashland	1970	2.5	112	526	5.7
Ashland	1971	2.3	68	747	5.9

Table 2. Formulation of materials for simultaneous applications on field studies.

Material	liters/20 liter can
15-6.5-12.5 (15-15-15)	7.33
32-0-0	6.72
H_2O	4.95
Total	19.00
Atrazine	85.36 gm

The fertilizer formulation used included a suspension containing 15% N, 6.5% P, and 12.5% K (15-15-15). This material is manufactured (TVA) by cold mixing water, urea-ammonium nitrate solution, attapulgite clay, and potash with a base suspension containing 13% N and 17.9% P. Urea-ammonium nitrate solution containing 32% N was added to the suspension along with 'AAtrex' atrazine (when applicable) to achieve an application rate of 168 kg N, 25 kg P, 46 kg K, and 3.4 kg atrazine per hectare (150 lbs N, 50 lbs P_2O_5, 50 lbs K_2O, and 3 lbs atrazine per acre). Table 2 gives the proportions of materials used when formulated in 20 liter plastic cans. Water was added to achieve proper herbicide and plant nutrient rates at a predetermined rate of liquid application.

Materials were formulated using high speed electric mixing and were air sparged immediately prior to application with a tractor-mounted plot sprayer at the rate of 750 l of liquid per hectare. The irrigated site (1971) received an additional 84 kg of N per hectare as 32% N solution applied through the irrigation water on July 5.

Treatments used on all the field studies are listed in Table 3. Field mixes involved adding the atrazine to the fertilizer immediately prior to application. The 14 and 28 day premixes were formulated and maintained in storage using 20 liter plastic containers until application. Prescribed premix times were not achieved in 1970 due to inclement weather and delay of applications. Separate applications

Table 3. Treatments used in field studies to determine effects of fertilizer-atrazine contact times and application methods.

Fertilizer Rates N	P	K	Atrazine Rate	Fertilizer-Herbicide Contact (Days)	Method of Application
kg/ha			kg/ha		
0	0	0	0	-	
0	0	0	3.4	-	Preemergent
168	25	46	3.4	Separate Application	Preplant
168	25	46	3.4	Separate Application	Preemergent
168	25	46	3.4	Field Mix	Preplant
168	25	46	3.4	Field Mix	Preemergent
168	25	46	3.4	14	Preplant
168	25	46	3.4	14	Preemergent
168	25	46	3.4	28	Preplant
168	25	46	3.4	28	Preemergent

required two passes of the applicator per plot. Fertilizer was applied on the first pass, herbicide in water on the second.

Preplant treatments were surface applied 14 days before the May 1 planting date and were incorporated with a tandem disc. Preemergent applications were made immediately after planting (no incorporation). The plot areas were overseeded with clover screenings to assure an adequate weed population for treatment evaluations.

Leaf samples were collected at the eight-leaf stage (first fully extended leaf from top of plant), at tasseling stage (first leaf opposite and below ear shoot), and at harvest (whole plant samples) on the two 1971 locations. Tasseling stage samples were collected at both 1970 locations, but whole plant samples at harvest were collected only at the Manhattan location. Leaf tissue samples were washed twice with deionized water and dried in a forced-convection oven at 70°C.

Leaf and whole plant samples were analyzed for N, P, and K using a sulfuric acid digestion procedure outlined by Dr. J. J. Hanway of Iowa State University. The dried tissue sample was ground in a Wiley mill using stainless steel knives and a 2 mm stainless steel screen. A 0.5 g samples of the material was placed in a 100 ml volumetric flask, 10 mls of concentrated sulfuric acid, a small piece of copper wire, and a glass bead were added. The flasks were placed on a hot plate, and the temperature was raised slowly until all frothing ceased (4-8 hours). Temperature was then increased until the acid boiled. Boiling continued for 12 hours. The flasks were allowed to cool and brought to volume with deionized water. A micro-Kjeldahl procedure outlined by Bremner and Keeney (1965) was used to determine N (without nitrate) from a 5 ml sample of the digest solution. A vandomolybdophosphoric yellow color method described by Jackson (1958, p. 151-153) was used to determine P. Five mls of the digest solution were diluted 1:10 with deionized water to determine K by flame photometry.

Due to severe drought conditions in 1970, the plots were harvested only for forage using a single-row plot forage harvester. Separate grain and stover yield data were collected in 1971. Grain was hand harvested and shelled by a small tractor-mounted sheller. The center two (of four) 9.15 m rows were harvested for forage and grain yield evaluations. In 1971 grain was harvested first, and stover was harvested immediately after. Individual plot forage, grain weights, and moisture samples were taken. Grain yields were adjusted to 12.5% moisture, forage yields to 70% moisture. Grain samples were dried, ground through a steel burr mill and N content determined using the macro-Kjeldahl technique described by Jackson (1958, p. 183-190). Grain protein percentages were then calculated.

Weed control evaluations were made using visual and pictorial comparisons of treatments. A least squares statistical procedure was used to determine significance of treatments on yield and plant nutrient composition. The 5% significance level was used on all determinations.

Growth Chamber Studies Using Atrazine

Two growth chamber evaluations were used to determine the effect of long contact times between atrazine and the suspension fertilizer. The first study involved contact times ranging from no contact up to 190 days (Table 4). 'Andrew' oats (*Avena sativa* L.) was used as an indicator of atrazine phytotoxicity. The second study was conducted in a similar manner except that contact times ranged up to 230 days (Table 5), and velvetleaf (*Abutilon theophrasti* Medic.) was used as the indicator of atrazine phytotoxicity. The treatments were replicated three times in both studies.

Application rates were the same as those used in the field (150 pp2m N, 22 pp2m P, 42 pp2m K, and 3 pp2m atrazine). Materials were incorporated into the top 3 cm of soil (Sarpy sandy loam). Soil test data are presented in Table 6. Formulated proportions of materials were the same as those used in the field studies except more water was added immediately prior to use to facilitate easier application. Thirty-five milliliters of solution (diluted) was applied to each pot. Incorporation was achieved by removing the top 3 cm of soil from the pots, and alternately applying the mixture (through an aspirator) and adding 0.5 cm of soil. This sequence started and ended with the application of the liquid, with 5 ml being applied to each 0.5 cm of soil. The formulated mixtures were

Table 4. Treatments used for growth chamber study utilizing oats as an indicator plant.

N	Fertilizer Rates P	K	Atrazine Rate	Fertilizer-Atrazine Contact Time
	ppm		ppm	
0	0	0	0	-
0	0	0	3	-
150	22	42	0	-
150	22	42	3	Separate Application
150	22	42	3	1 hour
150	22	42	3	10 days
150	22	42	3	25 days
150	22	42	3	40 days
150	22	42	3	70 days
150	22	42	3	100 days
150	22	42	3	130 days
150	22	42	3	160 days
150	22	42	3	190 days

Table 5. Treatments used for growth chamber study utilizing velvetleaf as an indicator plant.

Fertilizer Rates N	P	K	Atrazine Rate	Fertilizer-Atrazine Contact Time
	pp2m		pp2m	
0	0	0	0	-
0	0	0	3	-
150	22	42	0	-
150	22	42	3	Separate Application
150	22	42	3	1 hour
150	22	42	3	7 days
150	22	42	3	20 days
150	22	42	3	35 days
150	22	42	3	50 days
150	22	42	3	80 days
150	22	42	3	110 days
150	22	42	3	140 days
150	22	42	3	170 days
150	22	42	3	200 days
150	22	42	3	230 days

Table 6. Soil test data for growth chamber studies using atrazine.

Avail. N ppm	Avail. P kg/ha	Exch. K kg/ha	Organic Matter %	pH
11.0	10	479	1.0	7.5

stored in 120 ml polyethylene bottles. They were agitated immediately after formulating and again just prior to use.

Plastic cartons containing 1500 g of soil were used in both studies. The soil was covered with a thin layer of washed silica sand to retard moisture loss. The pots were seeded with a constant number of seeds; 10 for oats, 20 for velvetleaf, and 6 for 'Pioneer 321' corn. Velvetleaf germination was enhanced by soaking the seeds in 80°C water for one minute prior to planting. After emergence, plants were thinned to five for oats, five for velvetleaf, and three for corn.

The plants were grown in controlled environment chambers with a 16 hour day length until corn reached the six-leaf stage. Day temperature was 30°C, night temperature 20°C. Water usage of the plants was determined by average weight differences of selected pots before and after watering. All pots received equal amounts of deionized water. Pots were rotated every two days within the chambers in a predetermined fashion. Each study occupied a single chamber. Notes were taken periodically to help assess fertilizer and atrazine effectiveness; pictures were taken when herbicide activity was observed.

Only aerial portions of the plants were harvested. Dry weights were taken, and the dried plant material was analyzed for N, P, and K. Statistical and chemical procedures were the same as those used in the field studies.

Growth Chamber Study Involving Various Herbicides

A third growth chamber study was utilized to determine the effect of extended fertilizer-herbicide contact times on five different classes of herbicides. Chemicals used were S-ethyl diisobutyl thiocarbamate (butylate), 2-chloro-2',6'-diethyl-N-(methoxymethyl) acetaniline (alachlor), an alachlor/atrazine mix made during formulation in a 2:1.2 proportion, 3-(hexahydro-4,7-metanoindan-5-yl)-dimethylurea plus atrazine in a 2:1 proportion as a formulated product (norea/atrazine), and trifluralin. A description of the herbicides used is given in Table 7.

Included in this study was a nonreplicated comparison of the two media present in the liquid formulations. Samples of formulated mixtures were centrifuged, the supernatant and precipitate were separated, and dilutions were made for individual application of the two media. Also included was an atrazine formulation identical to those used in the previous growth chamber comparisons.

Butylate, alachlor, atrazine, and alachlor/atrazine were used with 'Pioneer 3306' corn, norea/atrazine was used with 'Pioneer 845' grain sorghum, and trifluralin was used with 'Cutler 71' soybeans. 'Andrew' oats was used with all the herbicides to determine their phytotoxicity. All treatments (Table 8) were replicated three times. Fertilizer mixing proportions were the same as those used in the previous field and growth chamber studies, but water was substituted

Table 7. Description of the various herbicides used in growth chamber study.

Herbicide Class	Common Name	Trade Name	Product Form
Thiocarbamate	Butylate	Sutan	emulsifiable concentrate
Amide	Alachlor	Lasso	emulsifiable concentrate
Thiocarbamate/ Triazine	Alachlor/ Atrazine	Lasso/ AAtrex	emulsifiable concentrate/ 80% wettable powder
Urea/Triazine	Norea/Atrazine	Herban 21A	80% wettable powder
Aniline	Trifluralin	Treflan	emulsifiable concentrate

Table 8. Treatments used in growth chamber study involving three classes of herbicides.

Fertilizer Rates N	P	K	Herbicide	Herbicide Rate	Fertilizer-Herbicide Contact Time
pp2m				pp2m	
150	22	42	-	0	-
150	22	42	Butylate	4	Separate Application
150	22	42	Butylate	4	1 hour
150	22	42	Butylate	4	25 days
150	22	42	Butylate	4	50 days
150	22	42	Butylate	4	100 days
150	22	42	-	0	-
150	22	42	Alachlor	3	Separate Application
150	22	42	Alachlor	3	1 hour
150	22	42	Alachlor	3	25 days
150	22	42	Alachlor	3	50 days
150	22	42	Alachlor	3	100 days
150	22	42	-	0	-
150	22	42	Alachlor/Atrazine	2+1.2	Separate Application
150	22	42	Alachlor/Atrazine	2+1.2	1 hour
150	22	42	Alachlor/Atrazine	2+1.2	25 days
150	22	42	Alachlor/Atrazine	2+1.2	50 days
150	22	42	Alachlor/Atrazine	2+1.2	100 days

(continued)

Table 8. (Continued)

Fertilizer Rates N	P	K	Herbicide	Herbicide Rate	Fertilizer-Herbicide Contact Time
pp2m				pp2m	
150	22	42	-	0	-
150	22	42	Norea/Atrazine	2.4	Separate Application
150	22	42	Norea/Atrazine	2.4	1 hour
150	22	42	Norea/Atrazine	2.4	25 days
150	22	42	Norea/Atrazine	2.4	50 days
150	22	42	Norea/Atrazine	2.4	100 days
50	22	42	-	0	-
50	22	42	Trifluralin	1	Separate Application
50	22	42	Trifluralin	1	1 hour
50	22	42	Trifluralin	1	25 days
50	22	42	Trifluralin	1	50 days
50	22	42	Trifluralin	1	100 days

for the 32% N solution on those mixtures used with trifluralin (for soybeans) to achieve lower nitrogen rates. Final dilutions with water and application procedures were the same as those used in the earlier growth chamber studies.

A Sarpy sandy loam soil taken from an area adjacent to the soil used in the other growth chamber studies was potted in plastic cartons and covered with a thin layer of washed silica sand. Soil test data for this soil are presented in Table 9.

Each crop was grown in a separate growth chamber. Environmental conditions used are given in Table 10.

Watering procedures and within-chamber randomization techniques were identical to those used earlier. Periodic notes and photographs were used to evaluate treatment differences. Corn was harvested at the six-leaf stage (17 days after planting), grain sorghum at the seven-leaf stage (27 days after planting), and soybeans at the five-trifoliate stage (27 days after planting). Only aerial portions were harvested. Statistical and chemical analysis techniques were the same as those described earlier.

Physical Compatibility Study

The physical compatibility of all six herbicide-fertilizer combinations used in the three growth chamber studies was determined. A 200 ml sample of the initial formulations (including herbicides) was transferred to a small glass bottle and agitated. Pictorial and visual observations were made

Table 9. Soil test data for growth chamber study involving three classes of herbicides.

Avail. N ppm	Avail. P kg/ha	Exch. K kg/ha	Organic Matter %	pH
15.2	18	616	1.1	7.4

Table 10. Growth chamber environments used for crops in the study of three classes of herbicides.

Crop	Day Temperature (°C)	Night Temperature (°C)	Photoperiod (hours)
Corn	30	20	16
Grain Sorghum	30	20	16
Soybeans	25	15	14

immediately after agitation and at periodic intervals. Comparisons of the mixtures were made with formulations containing no herbicide and with samples of the suspension fertilizer.

RESULTS AND DISCUSSION

Field Studies Using Atrazine

Corn yields, atrazine effectiveness on all field studies, and nutrient uptake on the 1971 Manhattan location are displayed in Figures 1 through 8. Detailed data including plant nutrient analysis and grain protein content are presented in Appendix Tables I through VI. For the figures, "NT" refers to no treatment, "AO" to the atrazine only treatments, "PP" to preplant applications of the various fertilizer-atrazine mixtures, "PE" to preemergent applications of the various fertilizer-atrazine mixtures, and "Sep. Appl'n" to separate applications of atrazine and suspension fertilizer.

Corn forage yields for the 1970 field studies are presented in Figure 1. Yields at both locations were low due to extreme drought. Differences due to treatment were significant at both locations (10% level for the Manhattan location with the $LSD_{.10}$ being 6.3), but largest yield differences were attributable to weed control rather than to fertilizer response. At both locations the fertilizer and atrazine-treated plots gave no significant yield increases over the atrazine only treatment. Limited moisture supply probably caused the lack of fertilizer response. Methods of application, preplant versus preemergent, and fertilizer-herbicide contact time variables provided no significant yield differences.

Broadleaf weed control on the 1970 plots was excellent with no visible differences due to the method of application or the length of fertilizer-herbicide contact time (Figs. 4 and 5). Weedy grass control, although good, was affected by the different treatments. Preemergent treatments produced better grass control than the preplant incorporated treatments, particularly at the Ashland location (Fig. 5). These differences, although visual were not great enough to cause a significant yield differential.

Plant tissue analyses were slightly affected by the various treatments. Applied nutrients increased plant concentrations of N and P in tasseling-stage leaf samples and in silage-stage whole plant samples in 1970. Atrazine application, method of application, and fertilizer-atrazine contact time had no effect on plant nutrient concentration or uptake.

Yields at both 1971 locations were much better than those of the 1970 studies. Grain and forage yield data from the 1971 studies are shown in Figure 2. Both weed control and fertilization produced significant yield increases at the irrigated Ashland location. Although excellent weed control was achieved at the dryland Manhattan site, no significant yield increases over the control plots were recorded. Lack of fertilizer response was related to plant nutrient carryover from the previous year. Preplant applications revealed a consistent advantage over preemergent applications, but this difference was statistically significant only at the Manhattan location on forage yield and total yield (grain plus forage). Better positional availability of plant nutrients from the preplant incorporated applications is a plausible explanation of the yield advantage. This advantage was not displayed in the 1970 studies because of the differential weed control in that year. The preplant treated plots in 1970 had poorer grass control resulting in greater competition for moisture and plant nutrients. No significant yield differences in the 1971 studies resulted from the length of fertilizer-herbicide contact time.

Broadleaf weed control was excellent in 1971 (Figs. 6, 7, and 8), with all atrazine-treated plots being essentially free of broadleaf weeds at harvest. Grass control was equal to broadleaf control at the Ashland location, but there was a slight invasion of crabgrass and fall panicum (Panicum dichotomiflorum Michx.) at the Manhattan location about the first of August. No comparative differences in control of these late season grasses could be detected in the atrazine-treated plots. Weedy species in order of greatest occurrence infesting the no treatment plots at Manhattan were crabgrass, fall panicum, pigweed, clover (Trifolium pratense), and ground cherry (Physialis heterophylla Nees.). Weedy species at the Ashland location were pigweed, clover, crabgrass, velvetleaf, and giant foxtail.

Eight-leaf and tassel-stage leaf samples, and whole plant samples at harvest revealed higher nitrogen, phosphorus, and potassium concentrations as affected by applications of these three elements at the Ashland location in 1971. The only statistically significant differences (5% level) due to treatment were K concentrations at tassel stage and N and K concentrations in whole plant samples. Whole plant samples at harvest had low nutrient contents because the grain was separated at harvest and was not included in the forage analysis. Plant uptake of N and K was increased at the 1971 Ashland location due to fertilizer application but there were no significant differences between contact times and methods of application. Nitrogen, P and K uptake under preplant application conditions was significantly increased in comparison to preemergent applications at the 1971 Manhattan location (Fig. 3) which supports the position of greater nutrient availability from preplant incorporated treatments. Separate applications and premixes significantly increased uptake of N and K in comparison to tank mixes of atrazine-suspension fertilizer in the same study.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

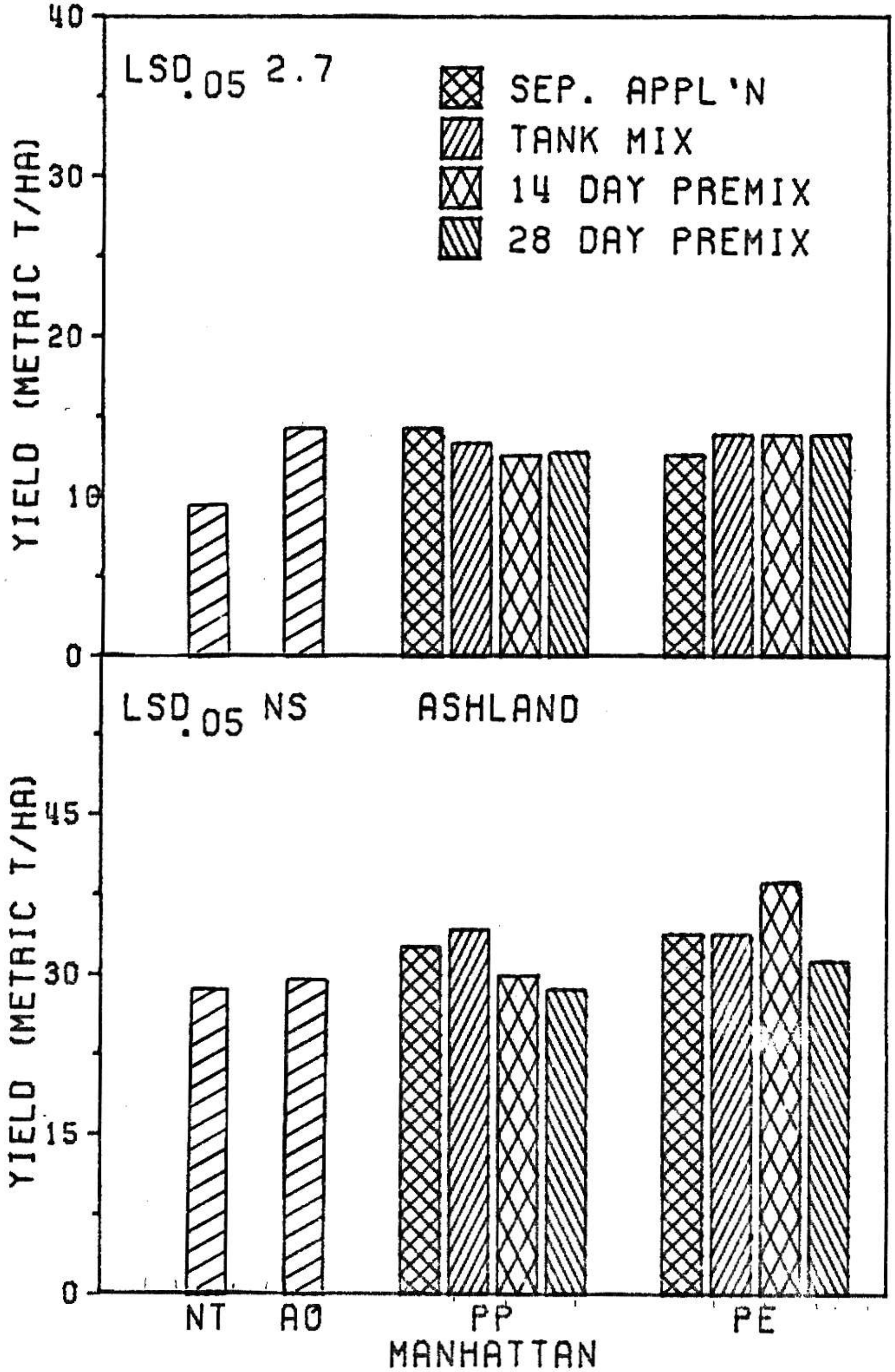


FIG.1. CORN FORAGE YIELDS RESULTING FROM SIMULTANEOUS FERTILIZER-ATRAZINE APPLICATIONS - 1970.

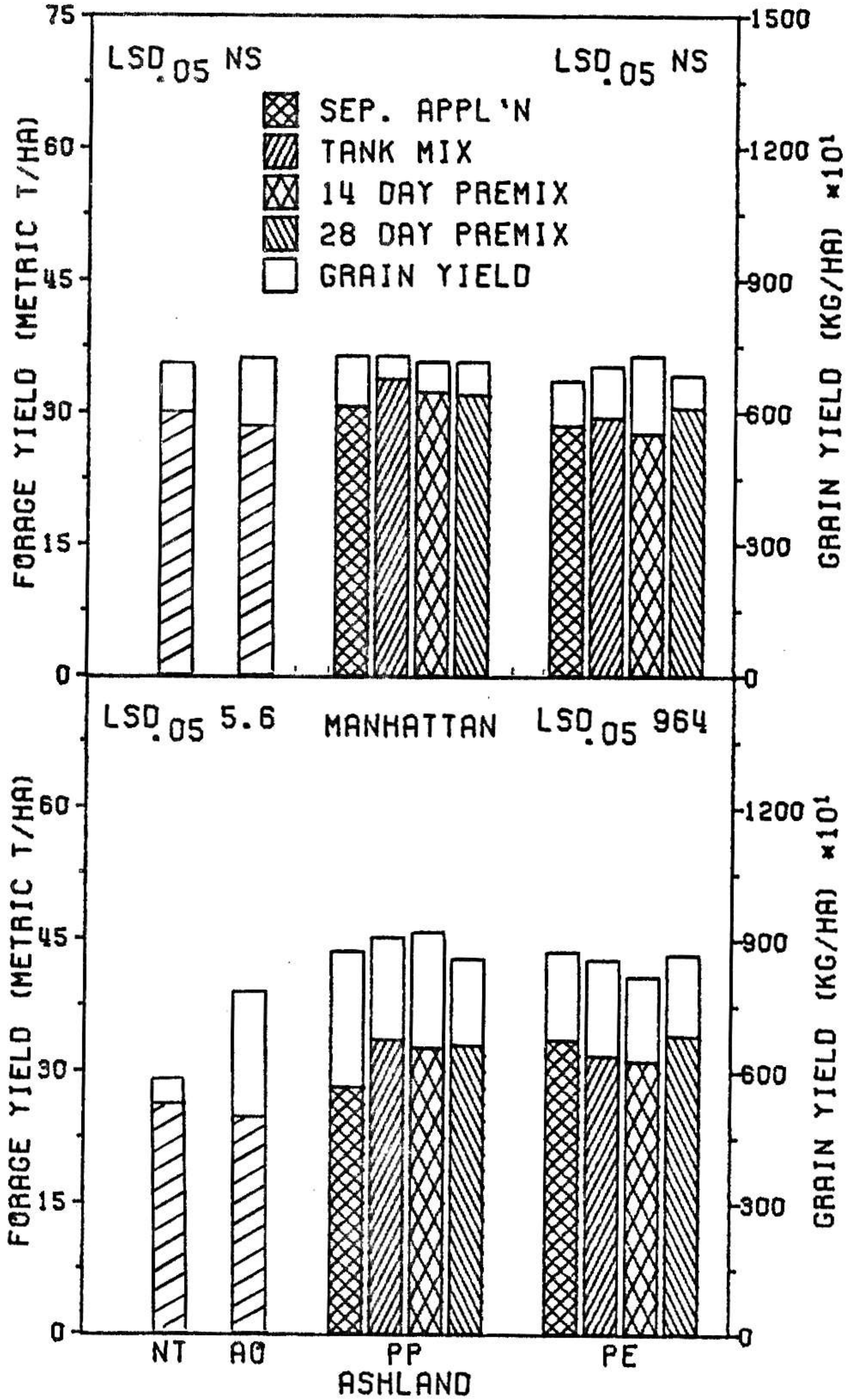


FIG.2. CORN YIELDS RESULTING FROM SIMULTANEOUS FERTILIZER-ATRAZINE APPLICATIONS - 1971.

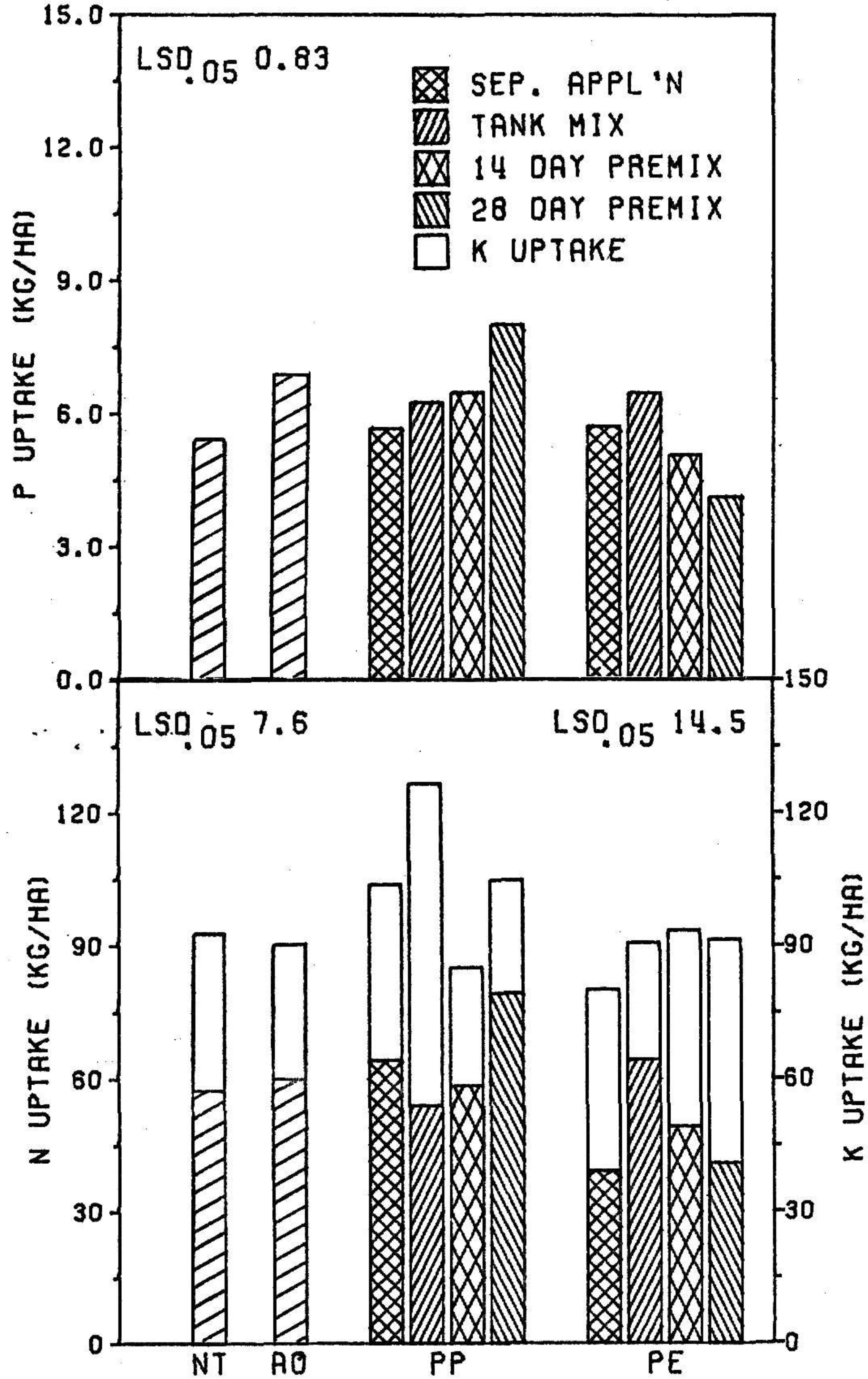


FIG.3. UPTAKE OF NITROGEN, PHOSPHORUS, AND POTASSIUM AS AFFECTED BY SIMULTANEOUS FERTILIZER-ATRAZINE APPLICATIONS - MANHATTAN 1971.

THIS BOOK CONTAINS NUMEROUS PAGES THAT WERE BOUND WITHOUT PAGE NUMBERS.

THIS IS AS RECEIVED FROM CUSTOMER.

Fig. 4. Broadleaf and weedy grass control in corn resulting from a preemergent application of atrazine - Ashland 1970.


NO TREATMENT


3LB ATRAZINE
PREEMERGE

Fig. 5. Comparison of weedy grass control achieved in corn with preemergent versus preplant applications of an atrazine-suspension fertilizer mix - Ashland 1970.


150 - 50 - 50
3LB ATRAZINE
TANK MIX
PREPLANT


150 - 50 - 50
3LB ATRAZINE
TANK MIX
PREEMERGE

Fig. 6. Broadleaf and weedy grass control in corn resulting from a preemergent application of atrazine - Ashland 1971.


NO
TREATMENT


3.75 LB ATRAZINE
IN WATER
PREEMERGE

Fig. 7. Comparison of broadleaf and weedy grass control in corn resulting from a separate application and a tank mix of atrazine-suspension fertilizer - Ashland 1971.


150 — 50 — 50
3.75 LB ATRAZINE
IN WATER
PREPLANT


150 — 50 — 50
3.75 LB ATRAZINE
TANK MIX
PREEMERGE

Fig. 8. Comparison of broadleaf and weedy grass control in corn with 14 and 28 day premix applications of atrazine-suspension fertilizer - Ashland 1971.


150 — 50 — 50
3.75 LB ATRAZINE
28 DAY PREMIX
PREPLANT


150 — 50 — 50
3.75 LB ATRAZINE
14 DAY PREMIX
PREEMERGE

Growth Chamber Studies Using Atrazine

Yields, plant nutrient concentration data, and atrazine effectiveness evaluations resulting from simultaneous fertilizer-atrazine applications after extended contact times are presented in Figures 9 through 14. Detailed data including plant nutrient uptake are presented in Appendix Tables 7 and 8. In the figures, "NT" refers to no treatment, "AO" to the atrazine only treatments, and "SA" to separate applications of atrazine and suspension fertilizer. The atrazine-fertilizer premix made immediately prior to application is referred to as both a "1 Hour" and a "0 Day" premix.

Results of the growth chamber study involving oats as an indicator plant for atrazine phytotoxicity indicated that the growth of corn plants was enhanced by the application of both fertilizer and atrazine (Fig. 9). Competition with oat plants partially accounted for the lower yields on those treatments where no atrazine was applied. No oat-free pots were maintained which could be used to determine if the atrazine directly affected nutrient absorption, particularly nitrogen, or plant growth.

The greatest atrazine phytotoxicity appeared in treatments involving premixes of not over 70 days and in separate applications of fertilizer and herbicide. Premixes of over 70 days produced some delay in oat kill with the greatest delay occurring on premixes of 190 days (Fig. 13). Delayed phytotoxicity was apparent for a period of about 5 days.

Despite the delays, all atrazine treatments produced complete oat kill within 10 days after plant emergence.

The growth chamber investigation using velvetleaf to assess atrazine phytotoxicity was initiated to further study the delay in atrazine activity noted earlier. Yield and plant nutrient content data from this study corresponded well with the earlier investigation (Figs. 9, 10, 11 and 12). Competition between corn and velvetleaf did reduce vegetative yields and nutrient absorption by corn, but it is possible that atrazine effects on nutrient absorption may be compounded with velvetleaf control. Contact time had no significant effect on vegetative yield or nutrient uptake of corn in either study.

Atrazine was as effective in this study on the premixed, simultaneous applications as it was on the separate applications. There was no visual evidence of delayed atrazine phytotoxicity in premixes of up to 230 days (Fig. 14), and velvetleaf kill was complete in all atrazine treated pots. Because the application rates and soil used were identical in both studies, it is assumed the difference noted in atrazine effectiveness between the two studies is a function of the plant species used. Larger scale studies using a variety of weedy plants would be productive in determining the role of plant species in phytotoxicity of the herbicide after extended contact times.

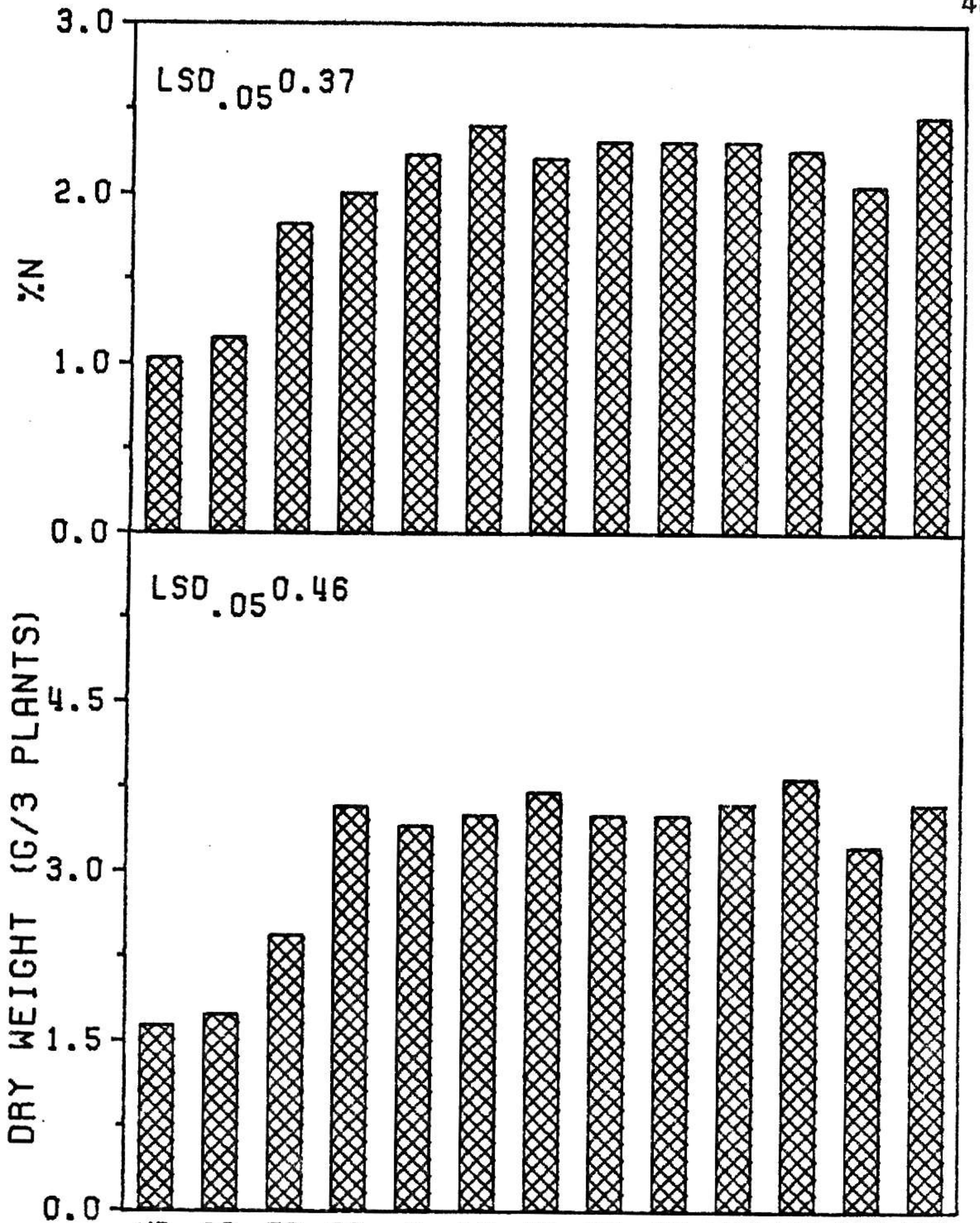


FIG.9. YIELD AND NITROGEN CONTENT OF CORN AS AFFECTED BY SIMULTANEOUS FERTILIZER-ATRAZINE APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY USING OATS

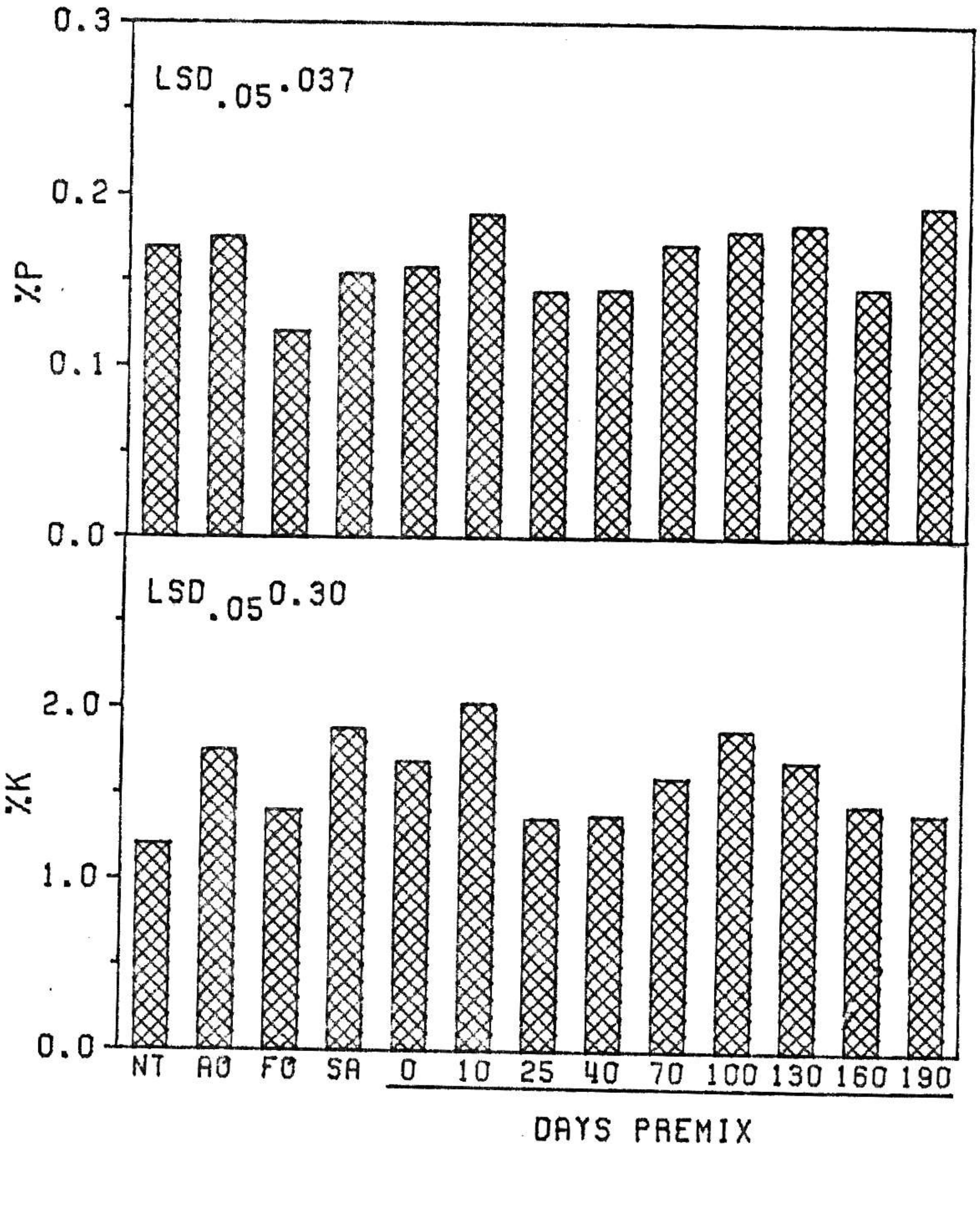


FIG.10. PHOSPHORUS AND POTASSIUM CONTENT OF CORN AS AFFECTED BY SIMULTANEOUS FERTILIZER-ATRAZINE APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY USING OATS.

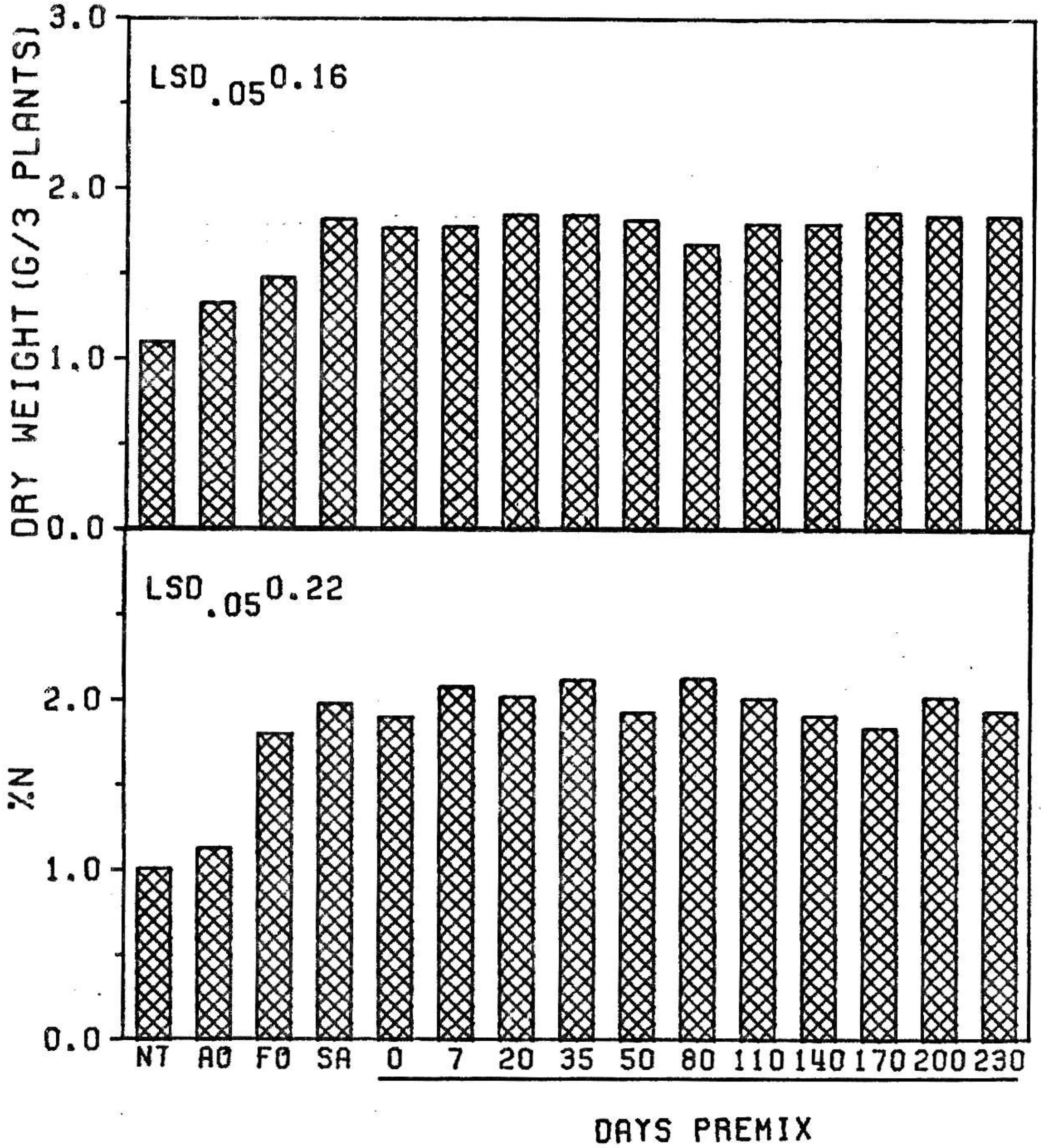


FIG. 11. YIELD AND NITROGEN CONTENT OF CORN AS AFFECTED BY SIMULTANEOUS FERTILIZER-ATRAZINE APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY USING VELVETLEAF.

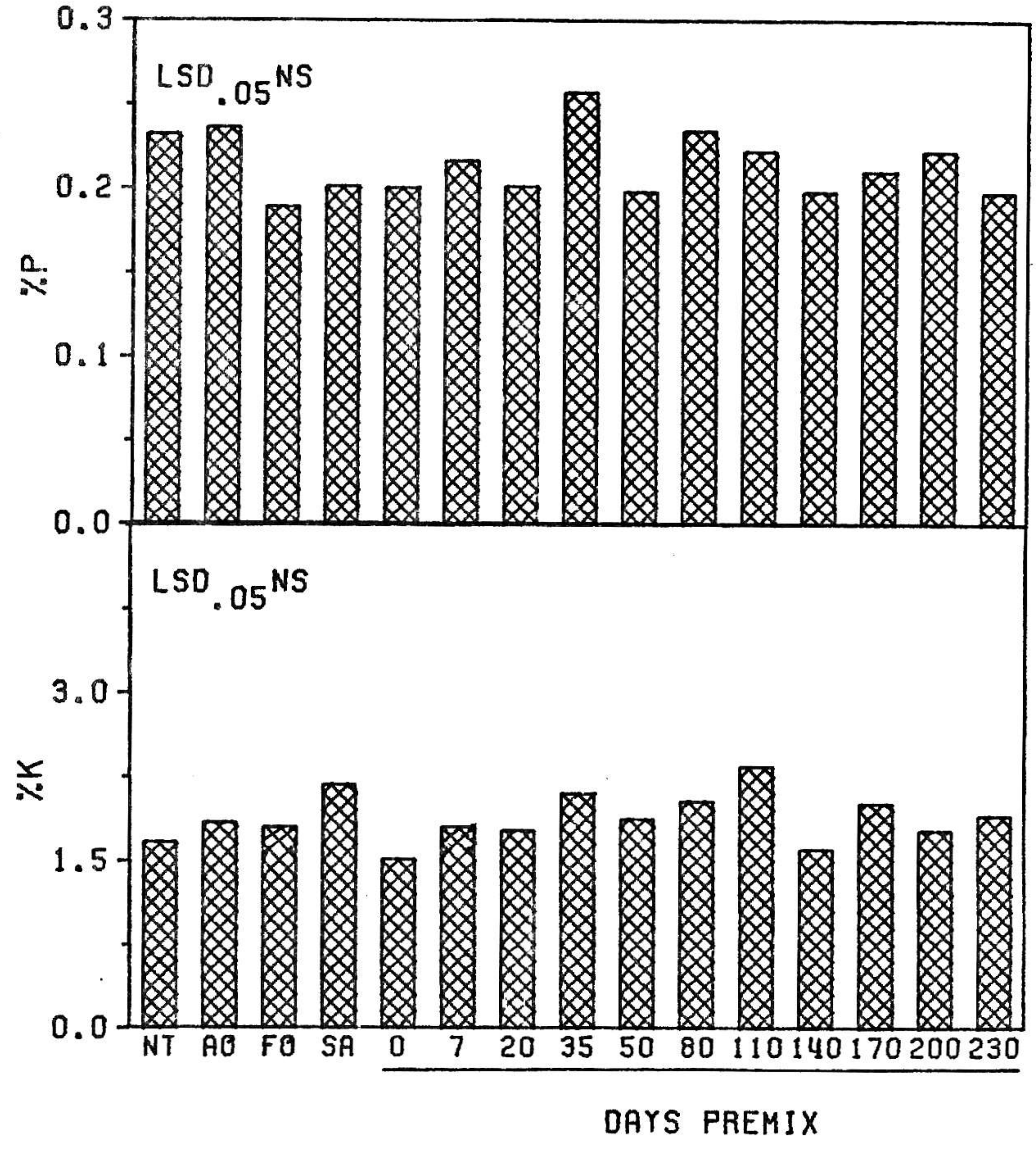
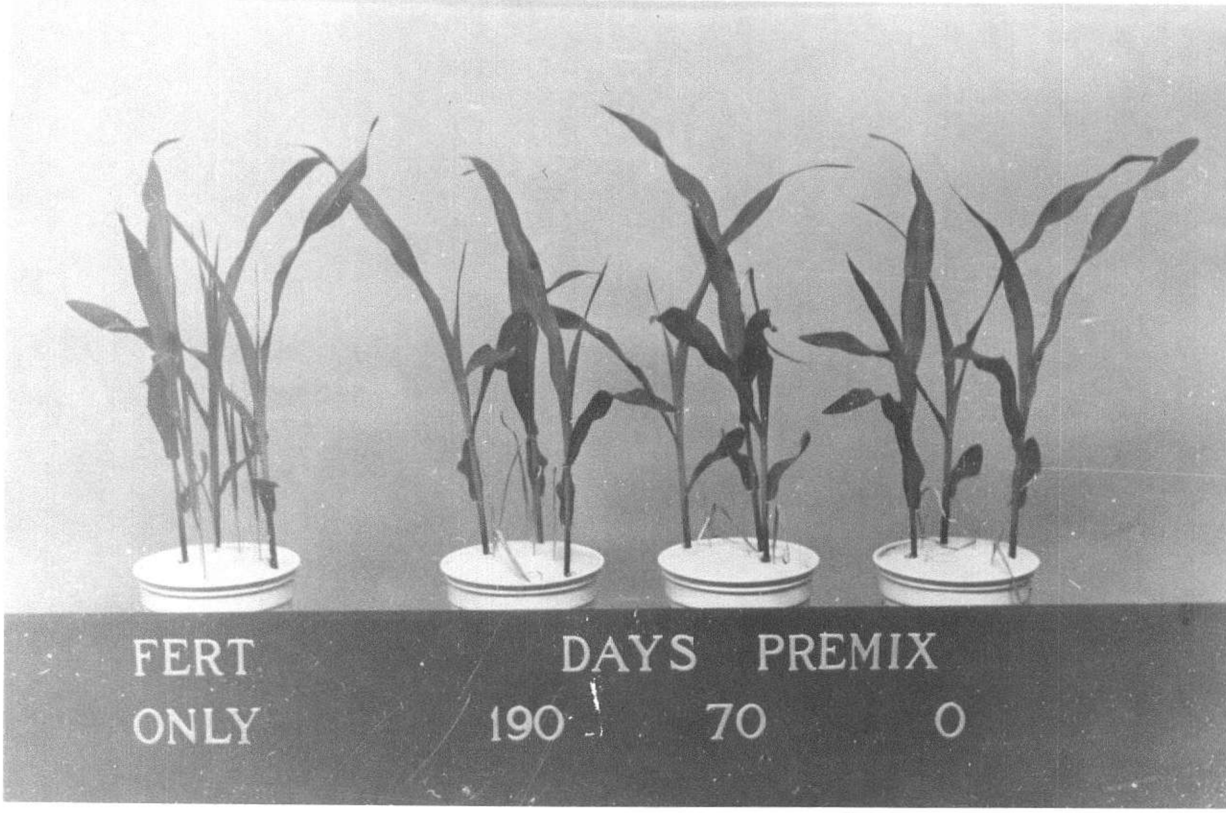


FIG.12. PHOSPHORUS AND POTASSIUM CONTENT OF CORN AS AFFECTED BY SIMULTANEOUS FERTILIZER-ATRAZINE APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY USING VELVETLEAF.

Fig. 13. Atrazine-suspension fertilizer premixes of over 70 days showing a delay in oat control - growth chamber study.


FERT
ONLY
DAYS PREMIX
190
70
0

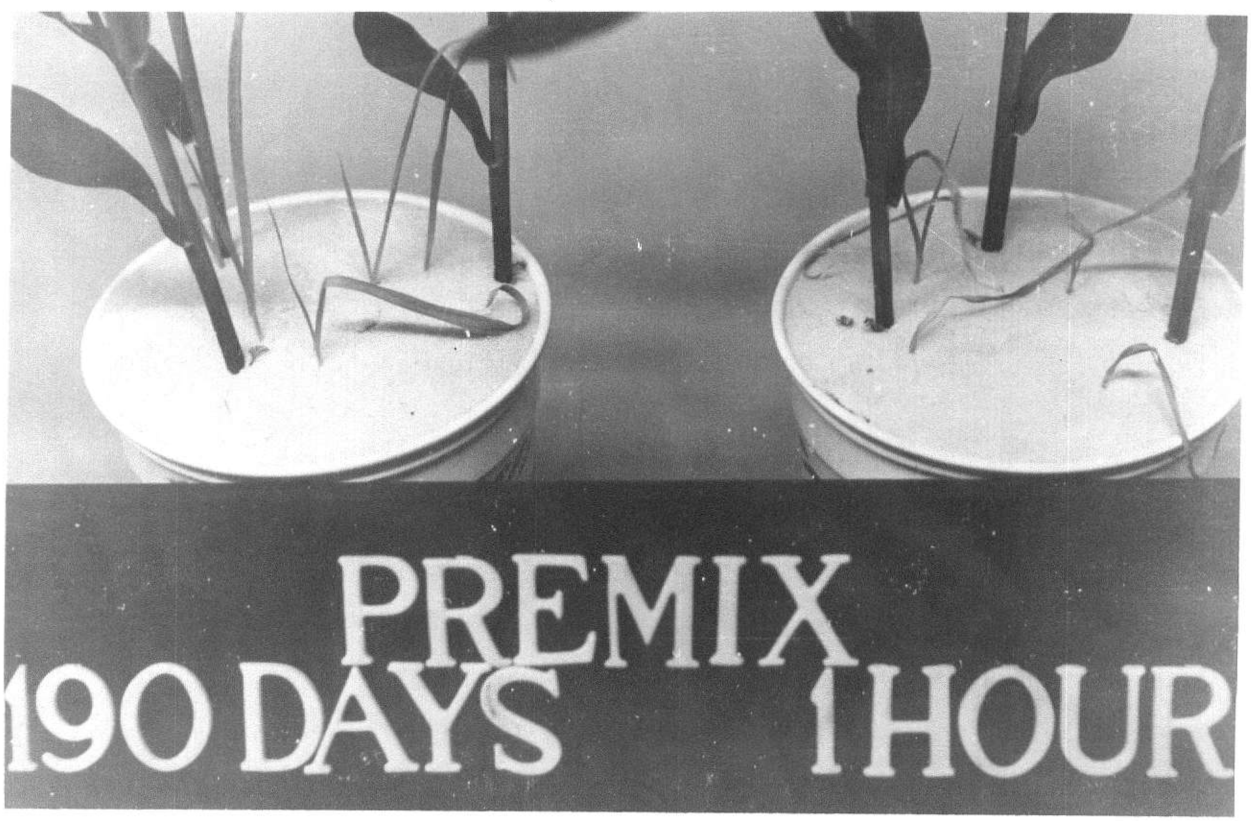
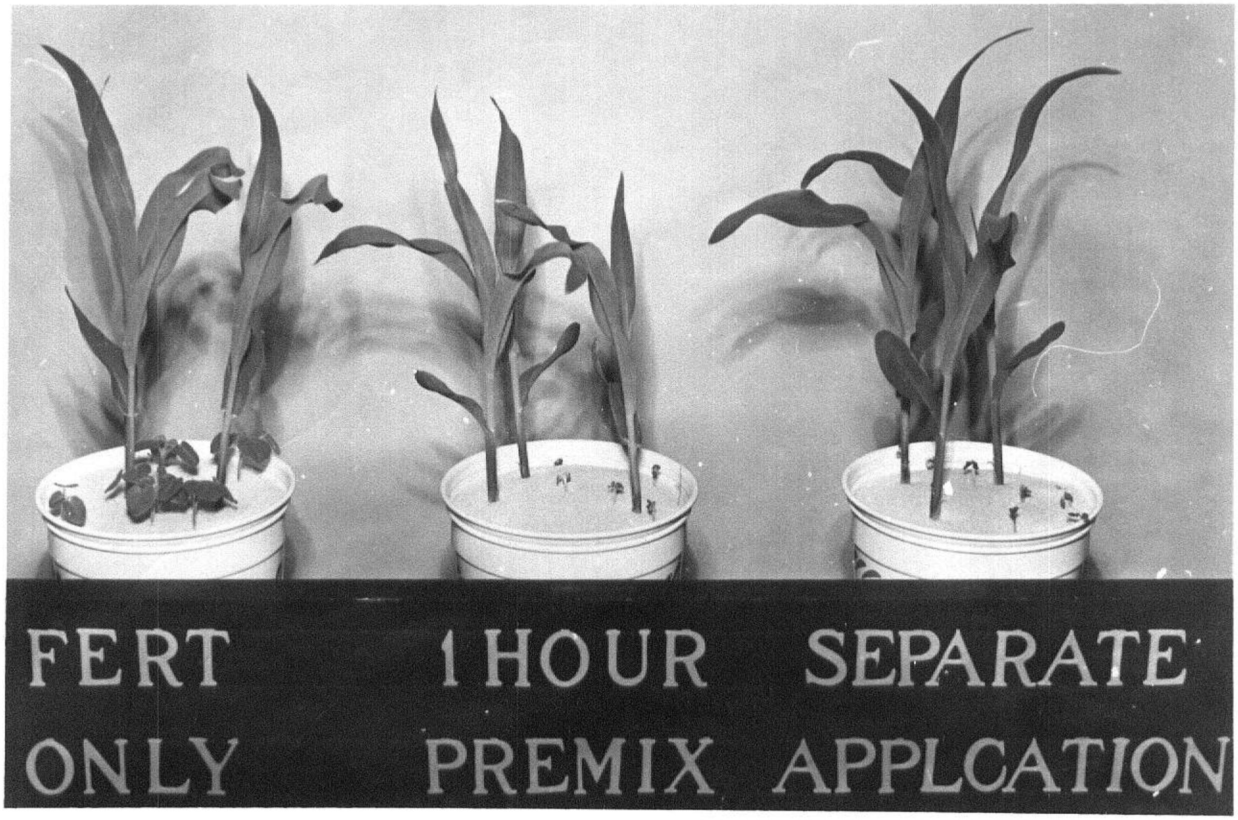

PREMIX
190 DAYS
1 HOUR

Fig. 14. Atrazine-suspension fertilizer premixes of 230 days provided velvetleaf control equal to separate applications and 1 hour premixes - growth chamber study.


FERT
ONLY
1 HOUR
PREMIX
SEPARATE
APPLCATION


FERT
ONLY
230 DAY
PREMIX
1 HOUR
PREMIX

Growth Chamber Study Involving Various Herbicides

Yield and plant nutrient composition data as affected by simultaneous applications of several herbicides with suspension fertilizer are reported in Figures 15 through 19. Crop growth and test plant (oat) control as a result of these applications are pictured in Figures 20 through 22. Detailed yield, plant nutrient content, and plant nutrient uptake data are presented in Appendix Tables 9 through 13. For the figures, "FO" and "Fert Only" refer to the fertilizer only treatments, "SA" and "Sep Appl'n", to separate applications of herbicide and fertilizer. The 1 hour premix is referred to as a "0 Day" premix in Figures 15 through 19.

The effectiveness of alachlor ('Lasso') when applied in combination with suspension fertilizer is demonstrated in Figure 20. There was no oat emergence on those pots which received the herbicide regardless of fertilizer-alachlor contact time. Percent nitrogen (Fig. 15) in corn tissue was increased significantly on those pots which received alachlor, but no differences due to treatment were observed in yield or N,P,K uptake.

An alachlor/atrazine mix also displayed complete oat control (Fig. 20) regardless of contact time. This herbicide combination did not affect yield, N,P,K content or N,P,K uptake in comparison to the fertilizer alone (Fig. 16).

Application of butylate ('Sutan') in combination with suspension fertilizer resulted in complete oat control on all treated pots (Fig. 21). No significant yield differences or N and P concentration differences were noted on corn due to treatment, but %K was affected by the various treatments (Fig. 17). Premixed combinations tended to decrease the K concentration in corn tissue. These same combinations, however, improved or equalled K uptake in comparison to the fertilizer only treatment except for the 25 day premix.

The lack of yield response from application of the three corn herbicides studied was probably a result of adequate light, nutrient, and water supply for optimum growth of both corn and oats. Continuation of this study would have possibly decreased corn yield in those pots which did not receive herbicide due to oat competition.

Trifluralin ('Treflan') controlled oats on all treated pots. Fertilizer-herbicide contact times of up to 100 days did not change the effectiveness of the herbicide or fertilizer (Figs. 18 and 21). Soybean yields were significantly increased on all trifluralin treated pots in comparison to the fertilizer only treatment. Nitrogen and P uptake was significantly increased over the fertilizer only treatment (Appendix Table XII).

Norea/atrazine ('Herban 21A') gave complete control of oats in all treated pots, but the atrazine present caused grain sorghum injury (Fig. 22). Injury was severe immediately after emergence, but the plants were overcoming the injury at harvest. On a less sandy soil this herbicide would probably not cause injury. Atrazine injury was sufficient to decrease grain sorghum yields significantly (Fig. 19). Percent N, P, and K in the plants and N and P uptake were increased significantly by norea/atrazine applications (Fig. 19, Appendix Table XIII).

All herbicides studied exhibited equal effectiveness whether applied separate from the fertilizer or applied in combination. Contact times up to 100 days did not alter herbicide or fertilizer effectiveness on any of the combinations studied. No oat-free pots were maintained to assess effect of the herbicides on plant yields and nutrient contents. Yield and plant nutrient differences observed may be partially the result of oat control. Field scale studies are needed to fully determine the effectiveness of the combinations studied, but these investigations indicate excellent long term compatibility of all five herbicides studied with a suspension type fertilizer.

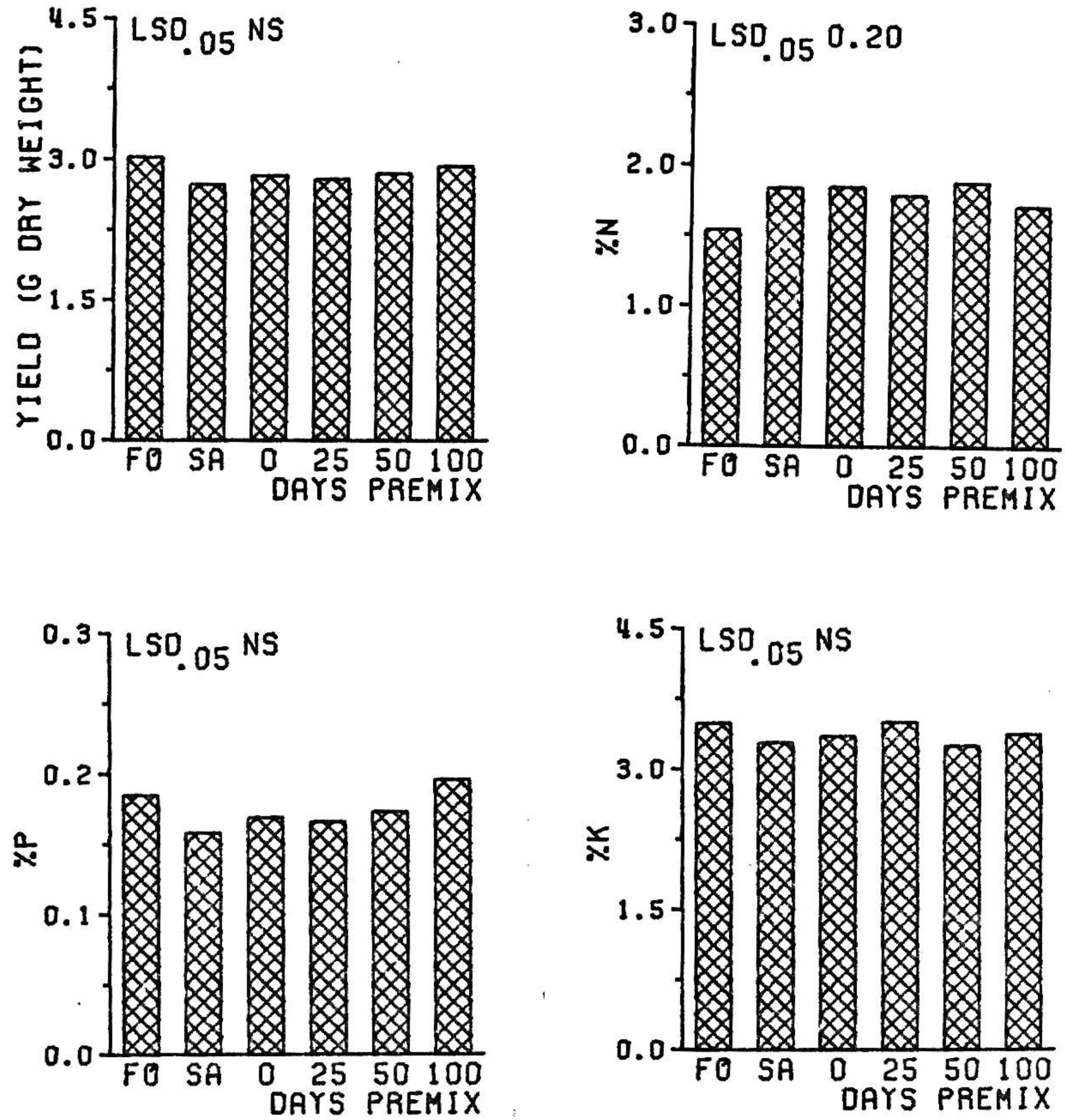


FIG.15. YIELD AND PLANT NUTRIENT CONTENT (N,P,K) OF CORN PLANTS AS AFFECTED BY SIMULTANEOUS FERTILIZER-ALACHLOR APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY.

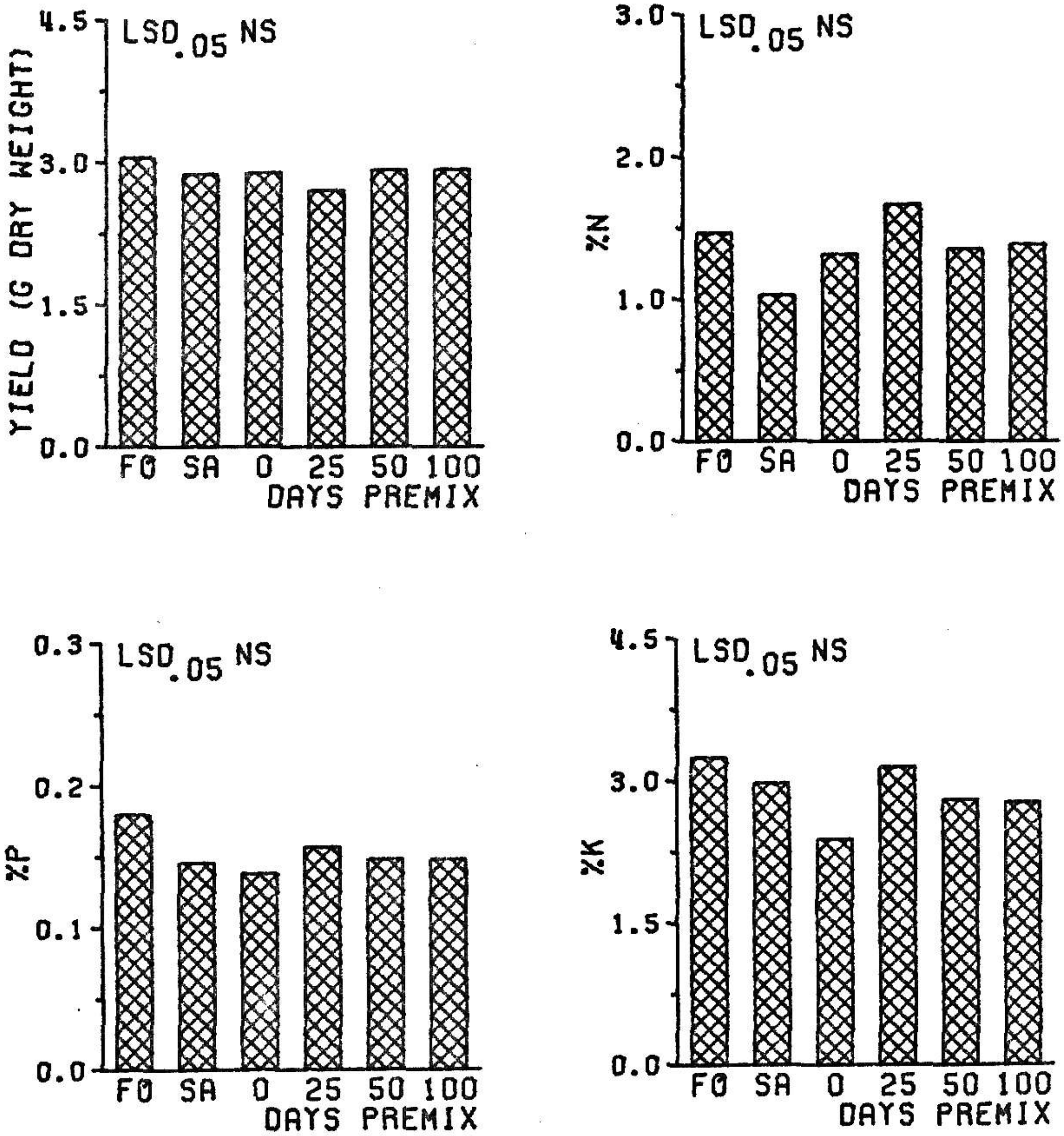


FIG.16. YIELD AND PLANT NUTRIENT CONTENT (N,P,K) OF CORN PLANTS AS AFFECTED BY SIMULTANEOUS FERTILIZER-ALACHLOR/ATRAZINE APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY.

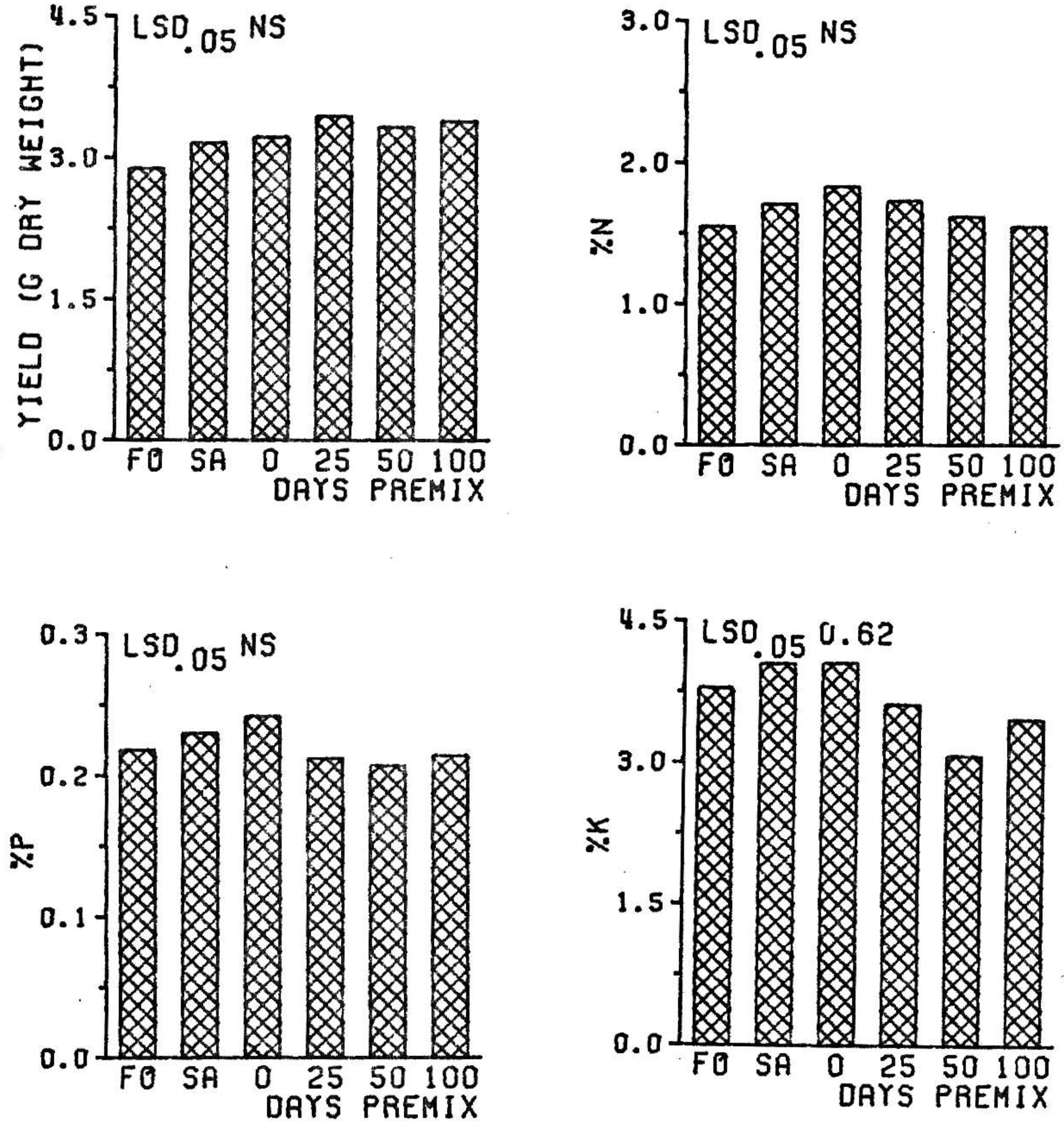


FIG.17. YIELD AND PLANT NUTRIENT CONTENT (N,P,K) OF CORN PLANTS AS AFFECTED BY SIMULTANEOUS FERTILIZER-BUTYLATE APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY.

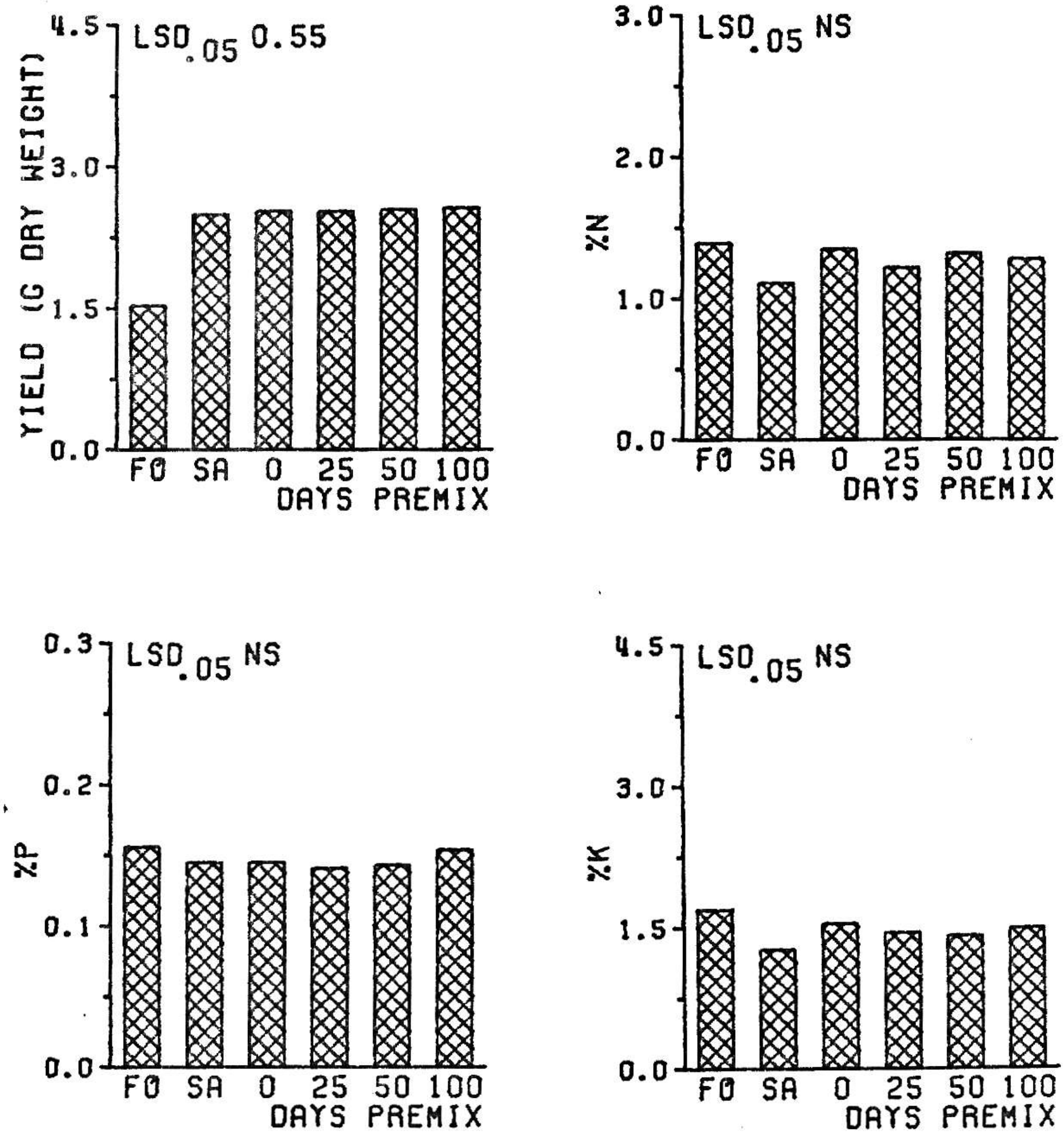


FIG.18. YIELD AND PLANT NUTRIENT CONTENT (N,P,K) OF SOYBEAN PLANTS AS AFFECTED BY SIMULTANEOUS FERTILIZER-TRIFLURALIN APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY.

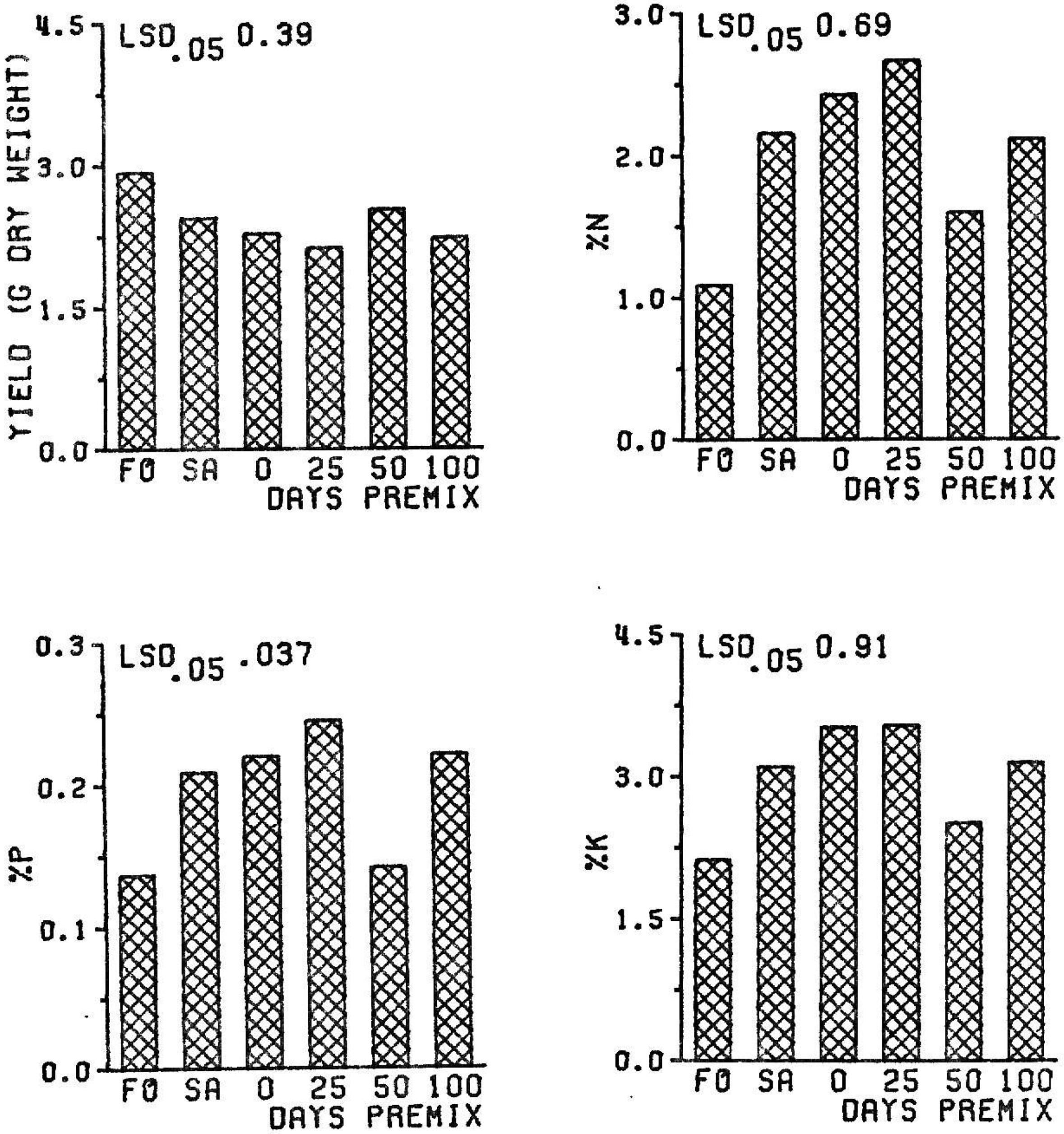


FIG.19. YIELD AND PLANT NUTRIENT CONTENT (N,P,K) OF SORGHUM PLANTS AS AFFECTED BY SIMULTANEOUS FERTILIZER-NOREA/ATRAZINE APPLICATIONS HAVING VARIOUS CONTACT TIMES - GROWTH CHAMBER STUDY.

Fig. 20. Alachlor-suspension fertilizer and alachlor/atrazine-suspension fertilizer premixes of 100 days displaying oat control equivalent to 1 hour premixes and separate applications - growth chamber study.


FERT ONLY
SEP APPL'N
100 DAY
1 HOUR
FERT LASSO PREMIX

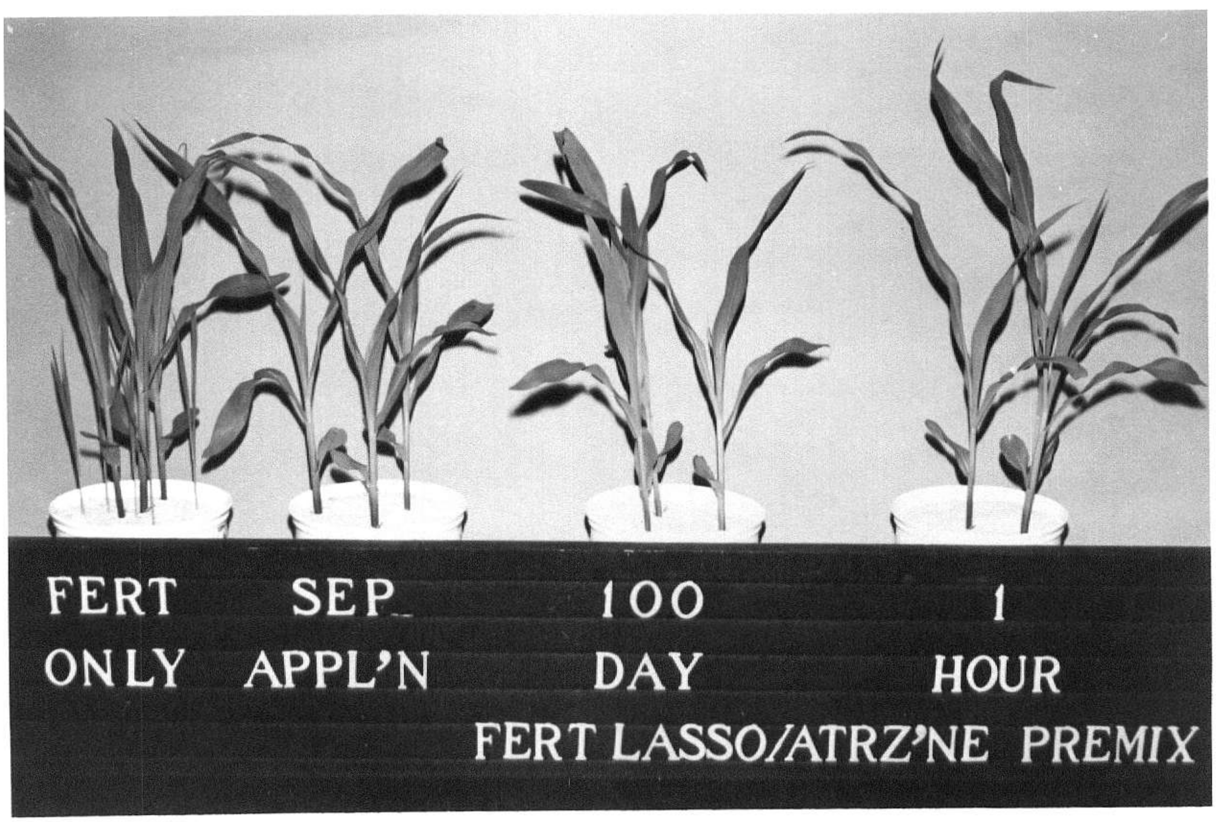
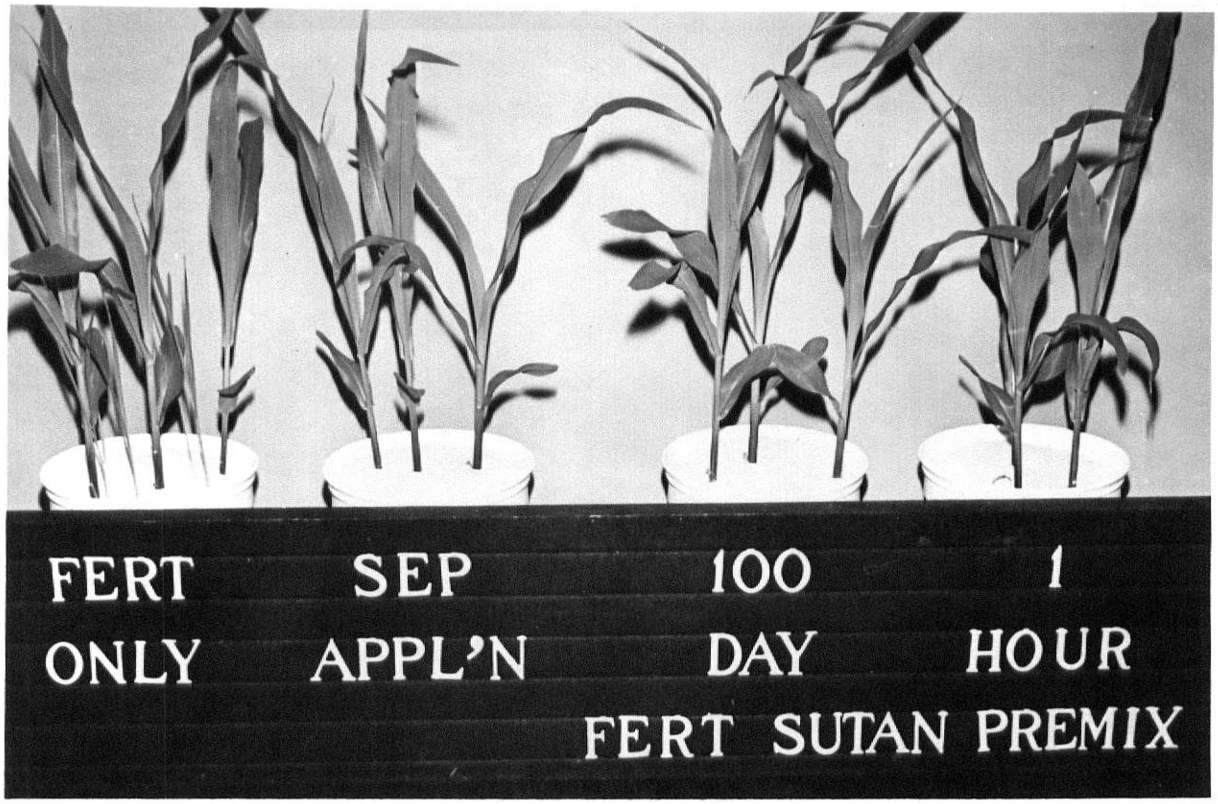

FERT ONLY
SEP APPL'N
100 DAY
1 HOUR
FERT LASSO/ATRZ'NE PREMIX

Fig. 21. Butylate-suspension fertilizer and trifluralin-suspension fertilizer premixes of 100 days displaying oat control equivalent to 1 hour premixes and separate applications - growth chamber study.


FERT ONLY
SEP APPL'N
100 DAY
1 HOUR
FERT SUTAN PREMIX

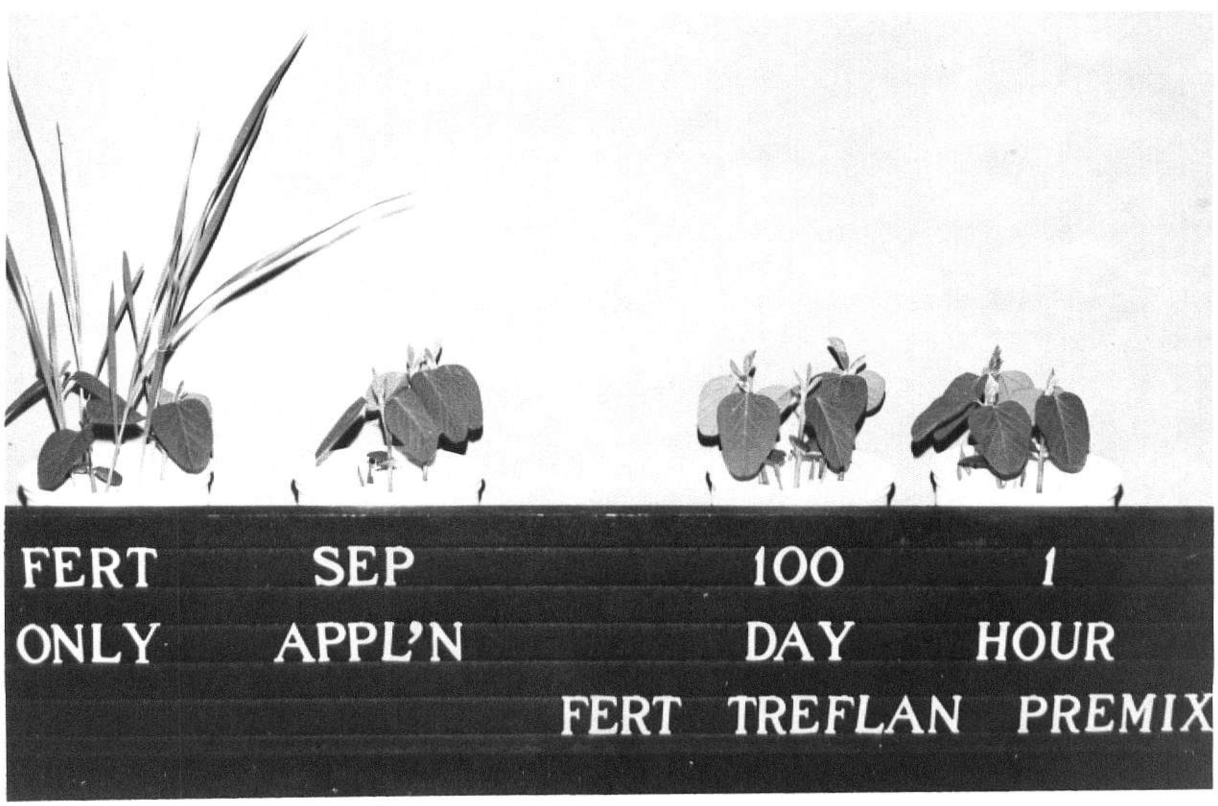
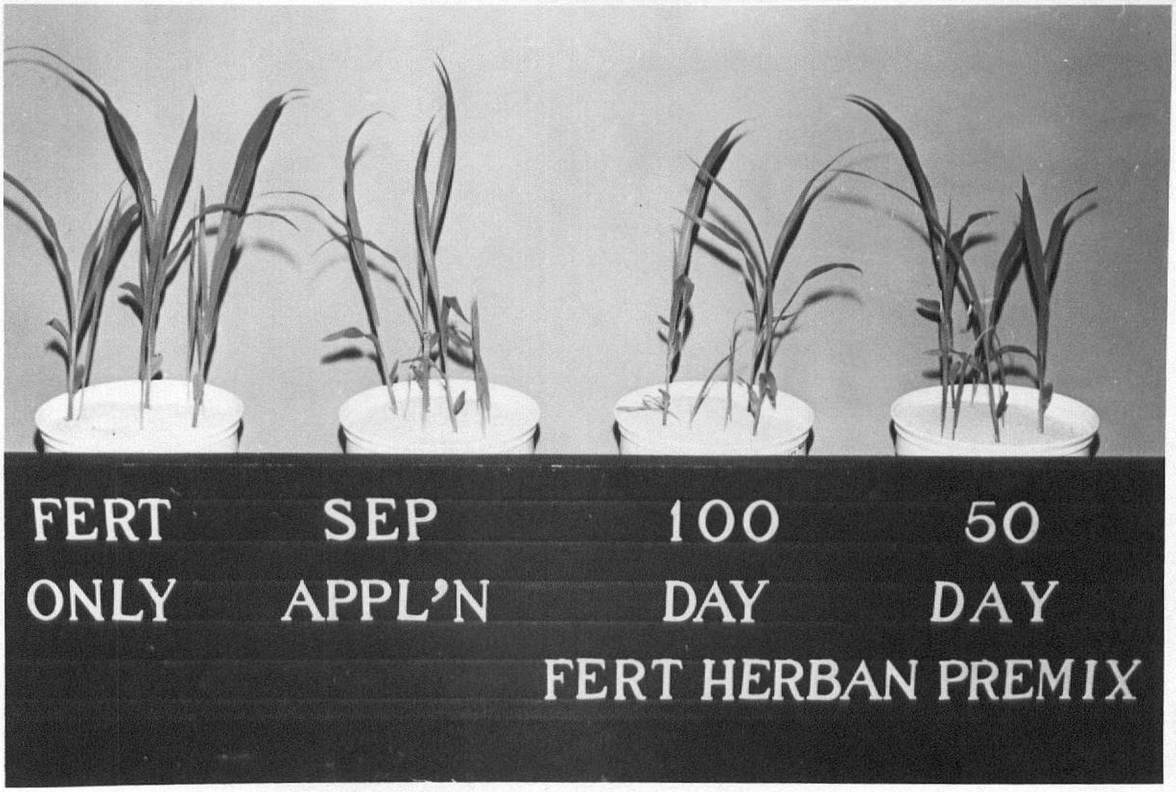
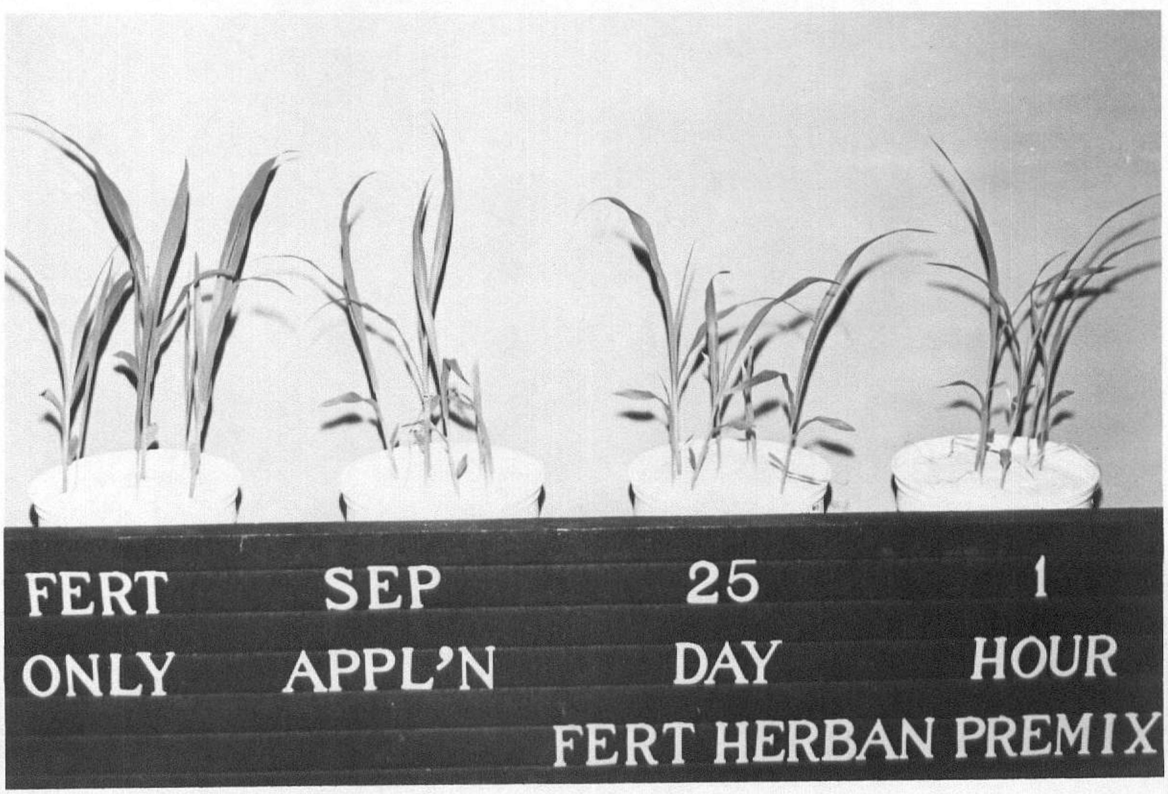

FERT ONLY
SEP APPL'N
100 DAY
1 HOUR
FERT TREFLAN PREMIX

Fig. 22. Norea/atrazine-suspension fertilizer treatments showing injury to grain sorghum, but giving complete oat control - growth chamber study.


FERT ONLY
SEP APPL'N
100 DAY
50 DAY
FERT HERBAN PREMIX


FERT ONLY
SEP APPL'N
25 DAY
1 HOUR
FERT HERBAN PREMIX

Physical Compatibility Study

Physical compatibility of the six studied herbicides (indicated by trade name - refer to Table 7) with suspension fertilizer as formulated for growth chamber use is pictured in Figures 23 through 26. All herbicides were compatible when observed immediately after agitation (Fig. 23) but separation began after one hour (Fig. 24). This separation increased over the eight week duration of the study with most of the separation occurring during the first 48 hours (Figs. 25 and 26).

Herbicide effects on separation of the true liquid and solid-containing liquid media can be determined by comparing bottles containing herbicides in fertilizer with those containing suspension fertilizer only (far left bottle of each series), and suspension fertilizer plus 32% N solution or water (second bottle from left in each series). Bottles containing the indicated herbicides also contain the same materials as the second bottle (suspension fertilizer plus 32% N solution or water) in each sequence. The addition of herbicide did not appreciably increase separation of any formulations, and no detrimental physical properties which might prevent application were observed.

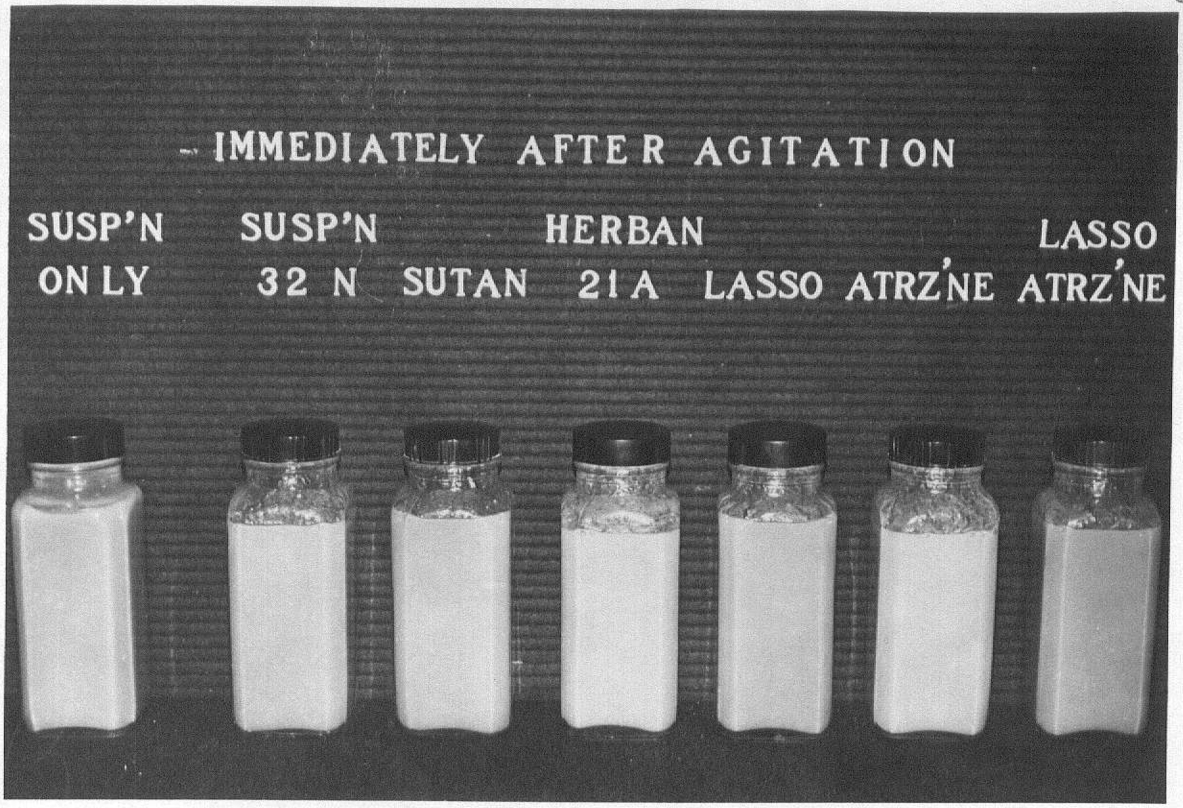
The difference in separation between the first two bottles in each sequence is a result of adding additional liquid to the initial suspension. When 32% N solution was added, it separated out, and when additional water was added, it separated out. Those bottles containing only suspension fertilizer did not show any separation after eight weeks but large salt crystals formed in the absence of agitation.

Of special interest in the separation of water below the suspension. Because water has a lower specific gravity than the suspension fertilizer has, it would be expected to separate above the suspension. Centrifuging these mixtures did cause water to separate as the supernatant. All formulations used would uniformly remix when agitated indicating excellent compatibility, but agitation is needed when the materials are stored to prevent separation. Air sparging may have created the unusual phenomenon by adsorption of air bubbles by the clay.

The need for agitation is further supported by the non-replicated bioassays performed on the two liquid media (Figs. 27, 28, 29, and Table 11). Alachlor, norea/atrazine, and trifluralin in particular separated with the heavier medium. Concentration of norea/atrazine, butylate, and trifluralin in the precipitate as a result of separation was great enough to cause visible crop injury.

Plant yields were decreased on all pots treated with the precipitates (PPT). Percent N was decreased in all plants treated with the supernatant (Supern't); percent P and K were generally greater in the precipitate-treated plants (Table 11). These results indicated herbicides and plant nutrients tend to separate into the heavier medium if mixtures are not agitated.

Fig. 23. Physical compatibility of the six herbicide-suspension fertilizer mixtures observed immediately after agitation as compared to formulations containing no herbicide and a sample of the suspension fertilizer alone.


IMMEDIATELY AFTER AGITATION
SUSP'N ONLY
SUSP'N 32 N
SUTAN
HERBAN 21A
LASSO
ATRZ'NE
LASSO ATRZ'NE

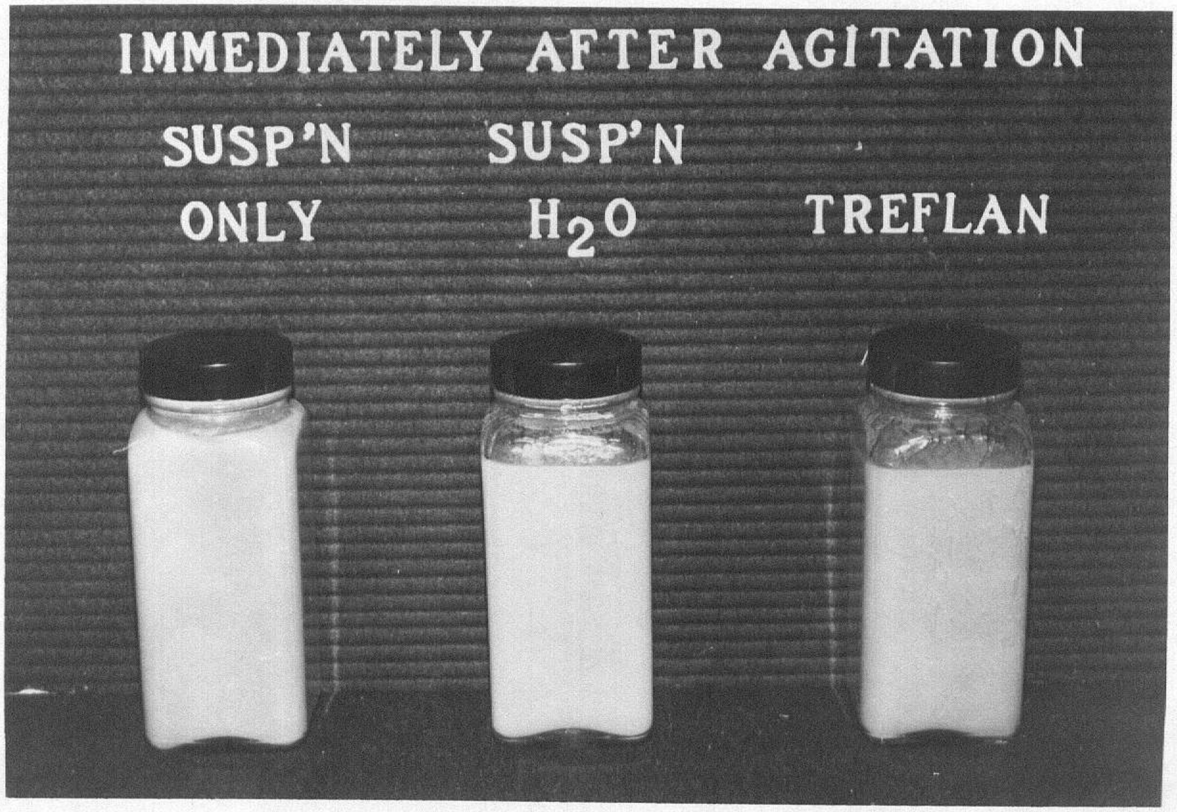
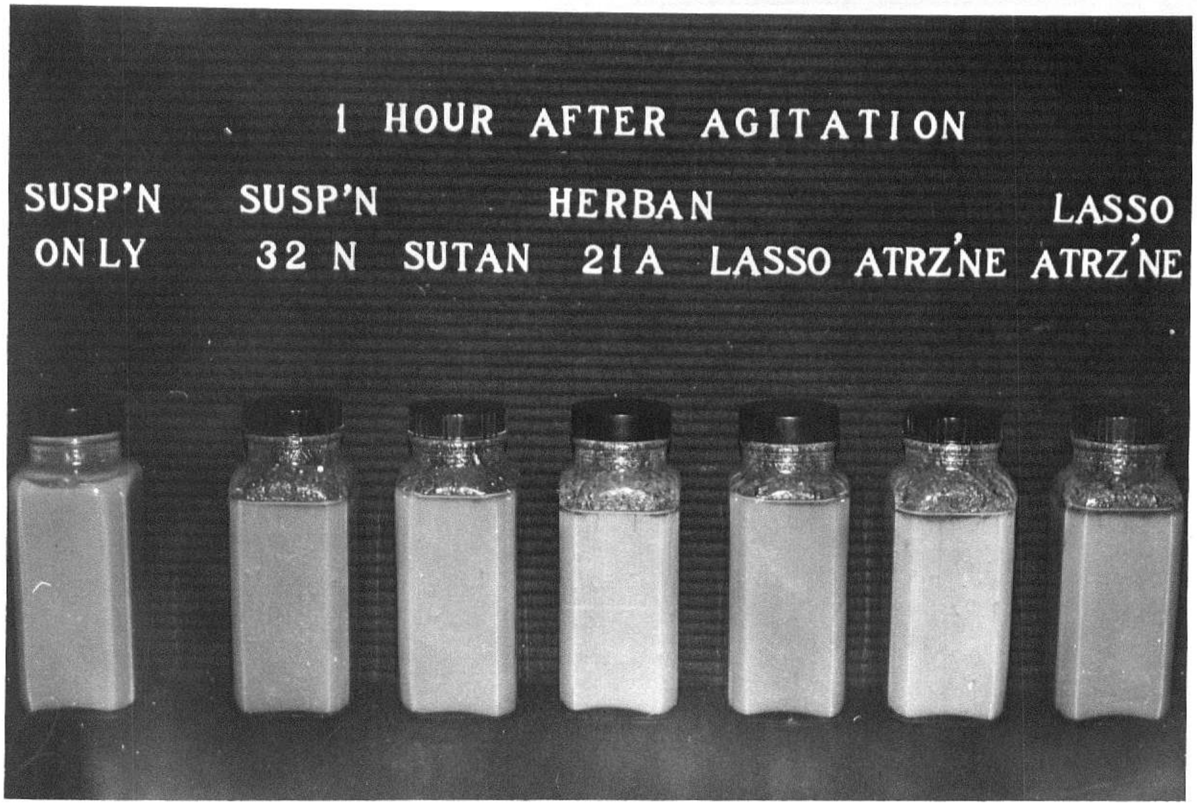

IMMEDIATELY AFTER AGITATION
SUSP'N ONLY
SUSP'N H2O
TREFLAN

Fig. 24. Physical compatibility of the six herbicide-suspension fertilizer mixtures observed one hour after agitation as compared to formulations containing no herbicide and a sample of the suspension fertilizer alone.


1 HOUR AFTER AGITATION
SUSP'N ONLY
SUSP'N 32 N
SUTAN
HERBAN 21 A
LASSO
ATRZ'NE
LASSO ATRZ'NE

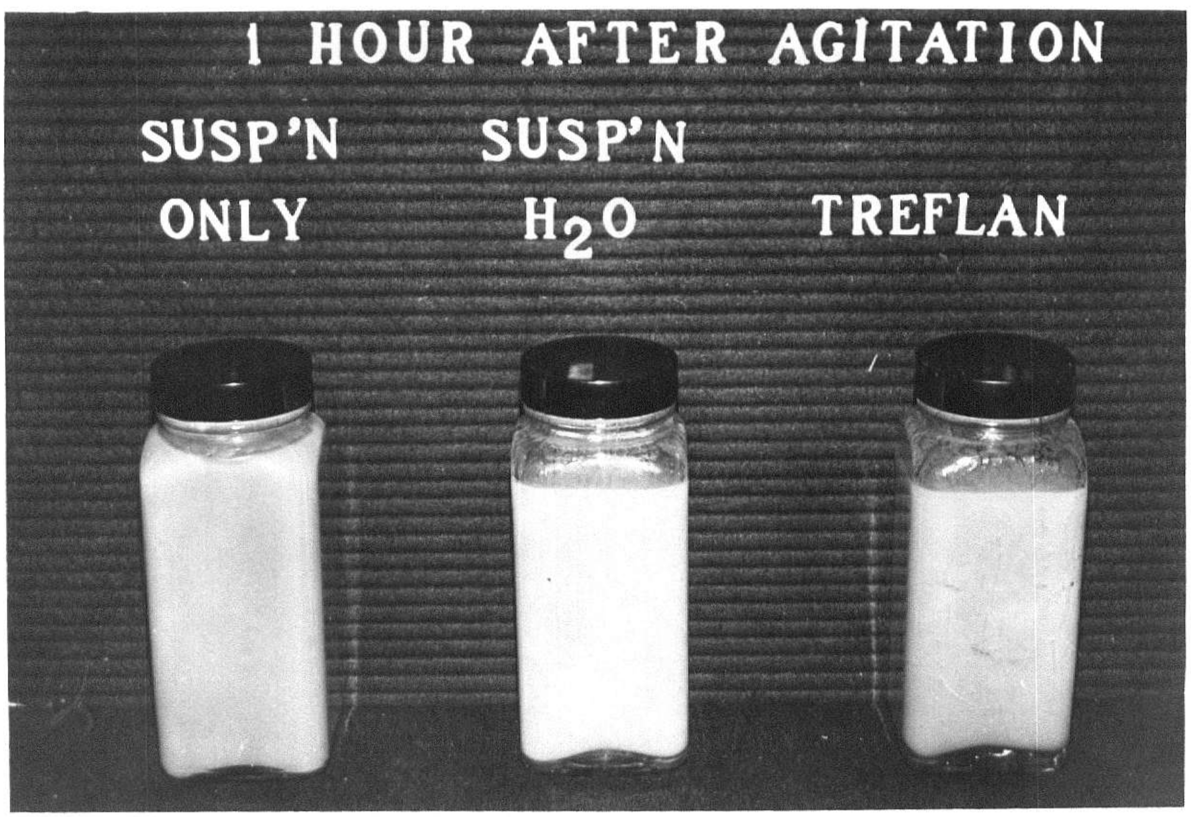
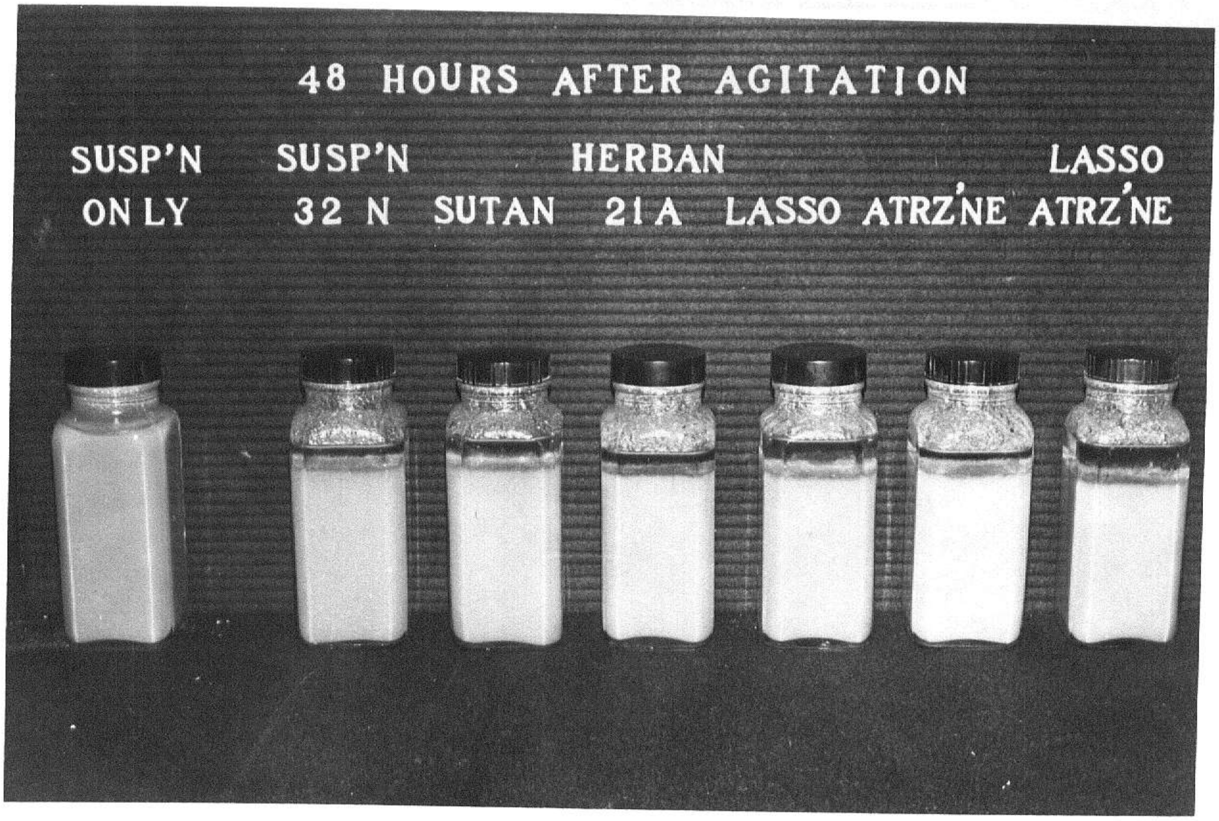
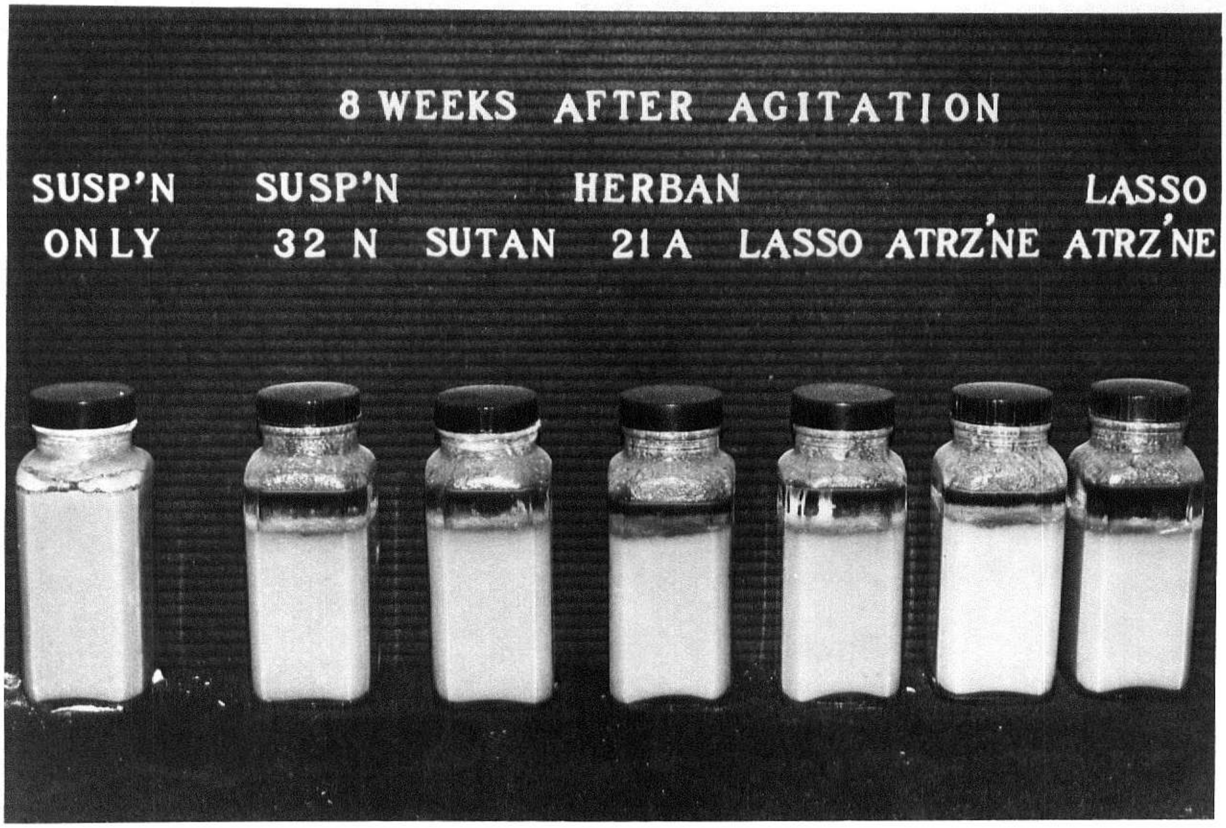

1 HOUR AFTER AGITATION
SUSP'N ONLY
SUSP'N H2O
TREFLAN

Fig. 25. Physical compatibility of the six herbicide-suspension fertilizer mixtures observed 48 hours after agitation as compared to formulations containing no herbicide and a sample of the suspension fertilizer alone.


48 HOURS AFTER AGITATION
SUSP'N ONLY
SUSP'N 32 N
SUTAN
HERBAN 21A
LASSO
ATRZ'NE
LASSO ATRZ'NE


48 HOURS AFTER AGITATION
SUSP'N ONLY
SUSP'N H_2O
TREFLAN

Fig. 26. Physical compatibility of the six herbicide-suspension fertilizer mixtures observed 8 weeks after agitation as compared to formulations containing no herbicide and a sample of the suspension fertilizer alone.


8 WEEKS AFTER AGITATION
SUSP'N ONLY
SUSP'N 32 N
SUTAN
HERBAN 21 A
LASSO
LASSO ATRZ'NE
ATRZ'NE

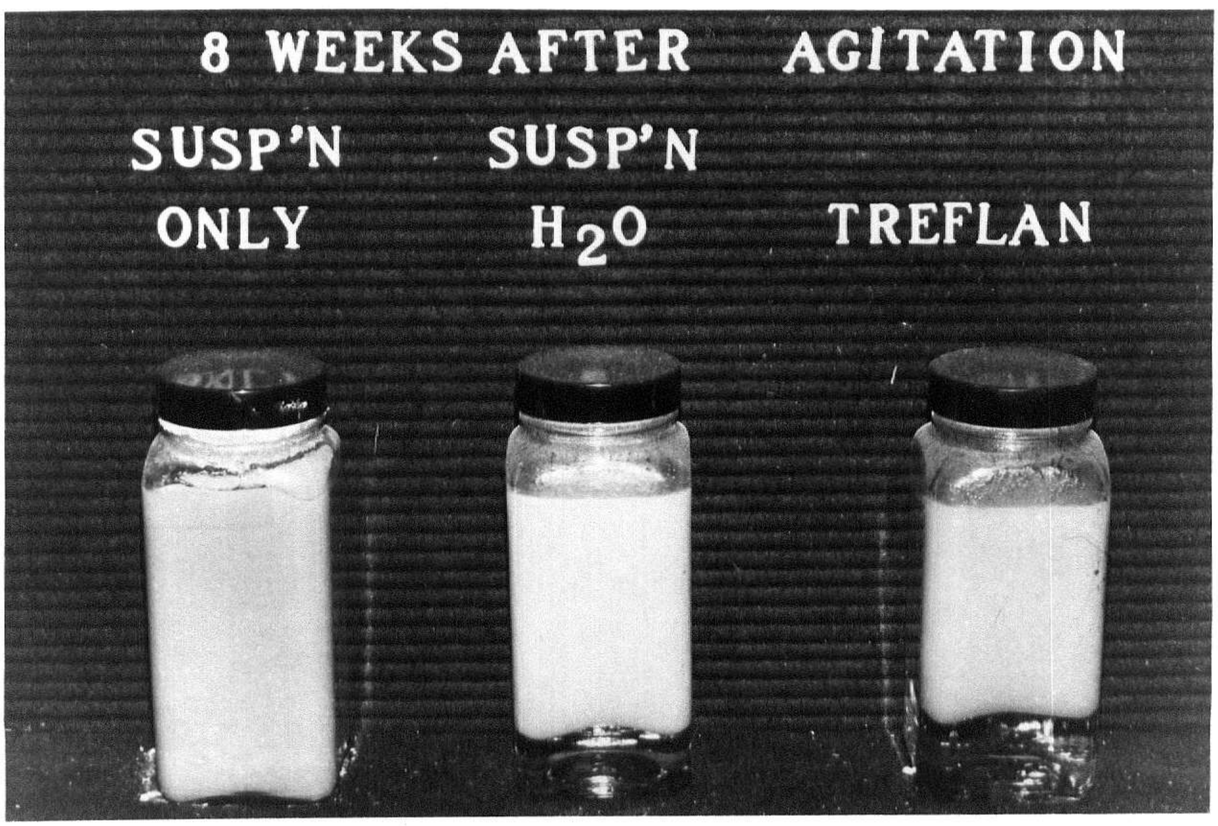
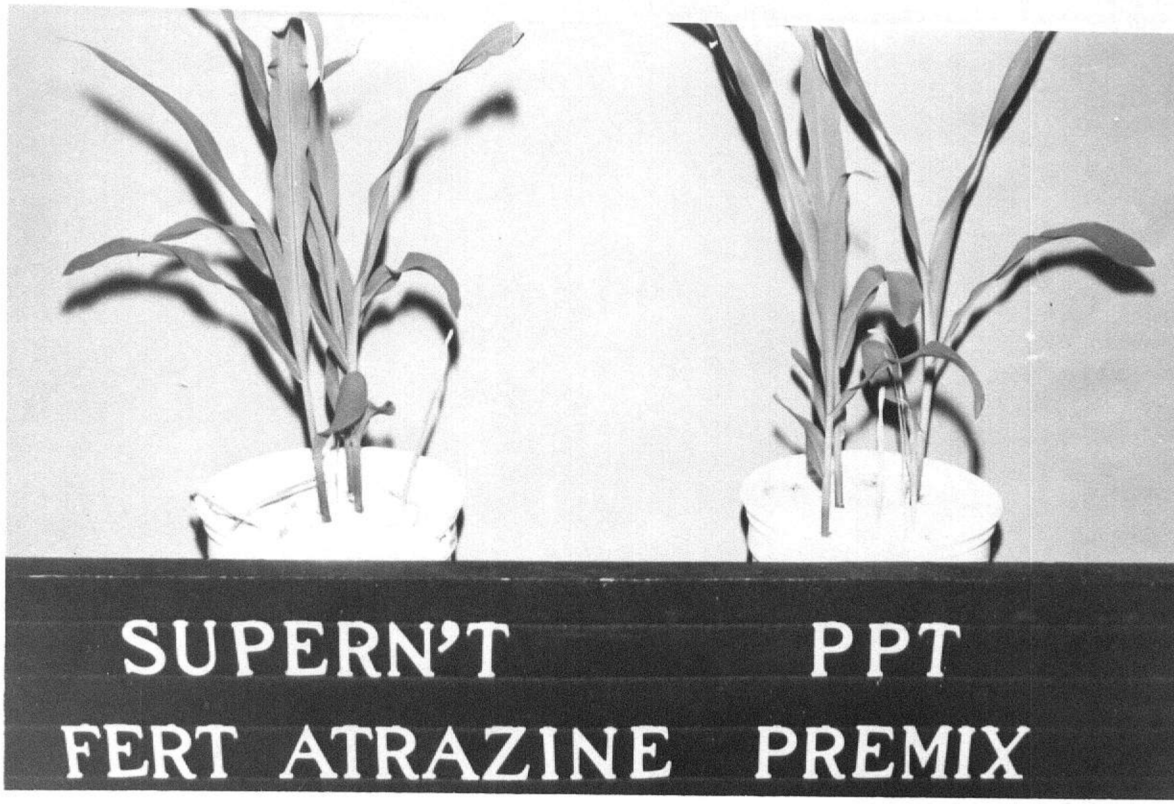

8 WEEKS AFTER AGITATION
SUSP'N ONLY
SUSP'N H2O
TREFLAN

Fig. 27. Corn growth and oat phytotoxicity resulting from applications of the supernatant and precipitate of centrifuged atrazine-suspension fertilizer and alachlor-suspension fertilizer mixtures.


SUPERN'T PPT
FERT ATRAZINE PREMIX

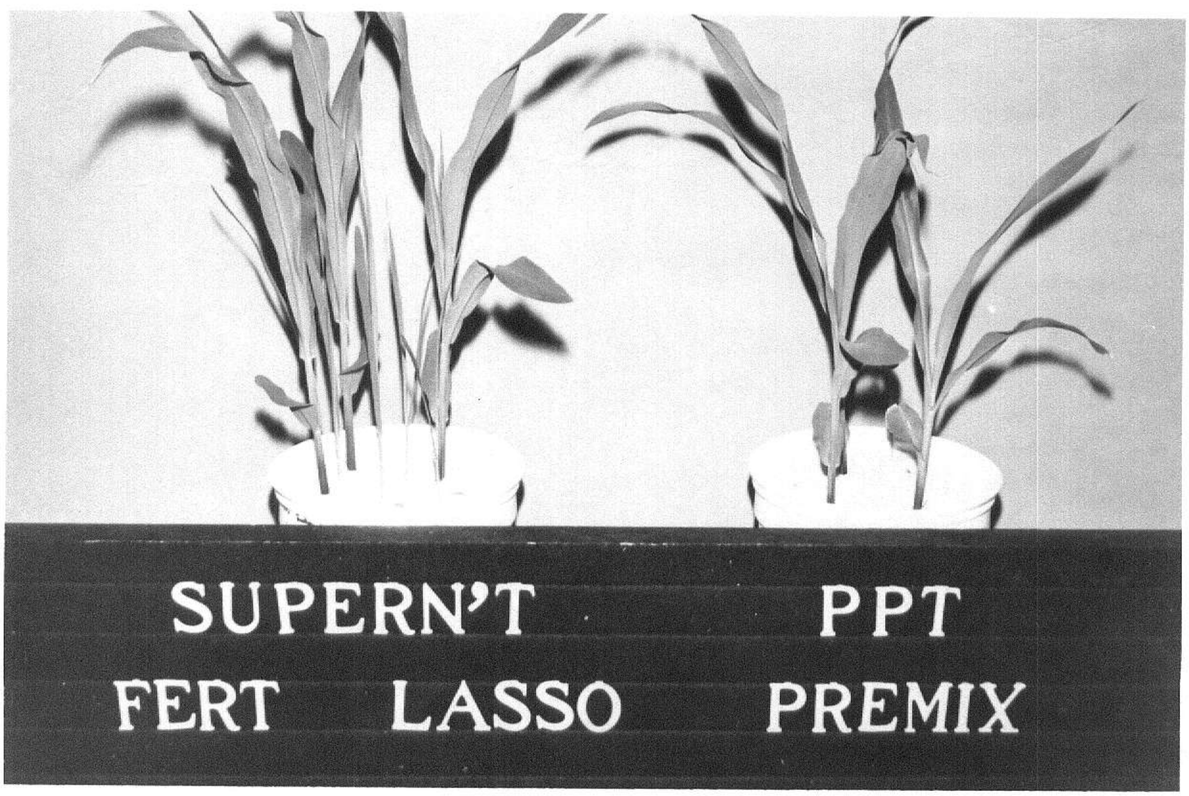
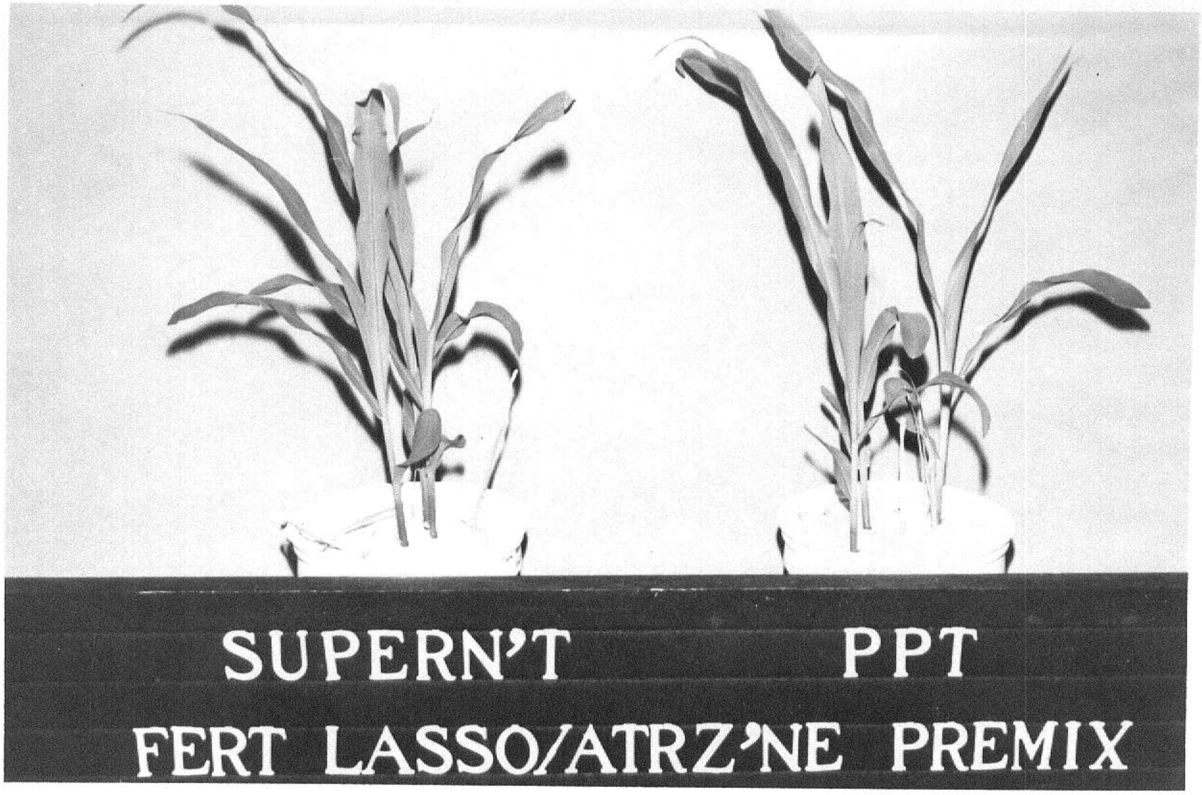
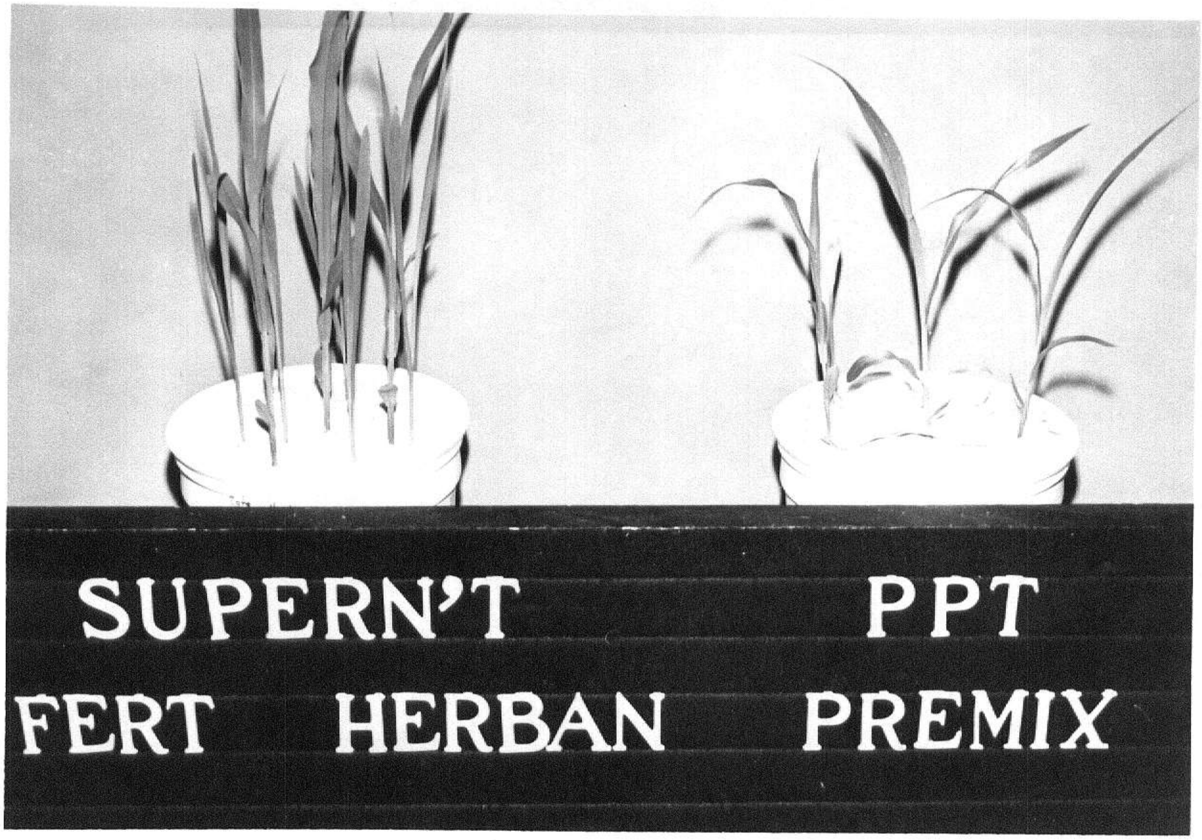

SUPERN'T PPT
FERT LASSO PREMIX

Fig. 28. Corn growth and oat phytotoxicity resulting from applications of the supernatant and precipitate of centrifuged alachlor/atrazine-suspension fertilizer and butylate-suspension fertilizer mixtures.


SUPERN'T PPT
FERT LASSO/ATRZ'NE PREMIX


SUPERN'T PPT
FERT SUTAN PREMIX

Fig. 29. Grain sorghum growth and oat phytotoxicity resulting from applications of the supernatant and precipitate of centrifuged norea/atrazine-suspension fertilizer mixtures; soybean growth and oat phytotoxicity resulting from applications of the supernatant and precipitate of centrifuged trifluralin-suspension fertilizer mixtures.


SUPERN'T
PPT
FERT HERBAN
PPT PREMIX

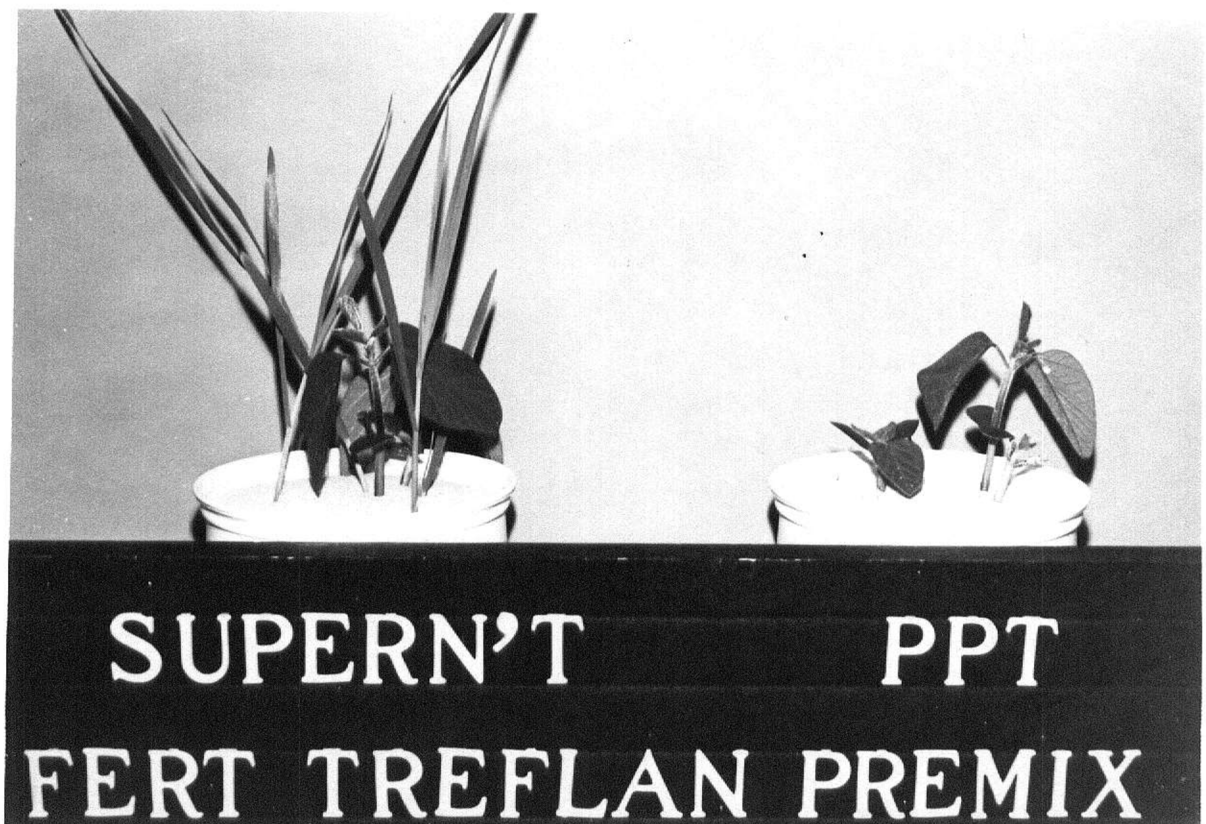

SUPERN'T
PPT
FERT TREFLAN
PPT PREMIX

Table 11. Yield and nutrient concentration of plants treated with the supernatant and precipitate of centrifuged herbicide-suspension fertilizer mixtures - non-replicated bioassay.

Herbicide	Medium	Crop	Yield[a.]	%N[b.]	%P	%K
Atrazine	Supern't.	Corn	2.93	0.72	0.13	1.68
	PPT	Corn	2.00	2.10	0.25	4.83
Alachlor	Supern't.	Corn	2.90	1.51	0.19	3.72
	PPT	Corn	2.42	1.83	0.15	3.62
Alachlor/ Atrazine	Supern't.	Corn	3.20	1.10	0.17	2.89
	PPT	Corn	2.15	1.40	0.15	3.57
Butylate	Supern't.	Corn	3.30	1.56	0.21	3.90
	PPT	Corn	2.20	2.00	0.27	4.78
Norea/ Atrazine	Supern't.	Sorghum	3.10	0.98	0.15	2.22
	PPT	Sorghum	1.70	3.15	0.38	3.72
Trifluralin	Supern't.	Soybeans	1.50	0.85	0.11	1.19
	PPT	Soybeans	1.30	2.17	0.17	1.76

a. Weight in grams/3 plants.
b. Kjeldahl nitrogen without nitrate.

CONCLUSIONS

The results of the reported field and growth chamber investigations indicate the excellent compatibility of six classes of herbicides with on suspension fertilizer over extended periods of time. There is no apparent danger in using materials that have been premixed during the current growing season. The application in suspension fertilizer of all herbicides studied appears to be as effective as the more common practice of applying herbicides in true solution fertilizers or water. As an additional advantage, fewer foaming problems occurred when the herbicides were mixed with suspension fertilizer instead of water.

Preemergent application of herbicide-fertilizer combinations is probably a more desirable method of achieving adequate weed control when atrazine is used. This practice has a disadvantage in that needed plant nutrients are not applied until after plant growth has been initiated and then in a position which may be subject to positional unavailability. Under irrigation, preemergent applications may be feasible because the additional water will help move some nutrients (N and K) into the plant root zone and also stimulate more root growth at the soil surface. Results of these studies indicate preplant incorporation of combined materials on irrigated corn will give excellent weed control and nutrient utilization. Preplant incorporated treatments under dryland conditions may require increased atrazine rates to offset the diluting effect of incorporation on atrazine phytotoxicity.

Although vigorous agitation is required when mixing and applying the materials, no undesirable physical properties of the mixtures were detected. Care should be taken in applying the results of this investigation to other herbicides, different suspension fertilizers, and different rates of application, as each mix may exhibit its own physical and chemical properties. All legal restrictions regarding fertilizer-herbicide mixtures must also be observed, and the proper method of application for the herbicide and fertilizer must coincide before the full advantage of dual applications can be realized.

LITERATURE CITED

Achorn, F.R., W.C. Scott, and J.A. Wilbanks. 1970. Physical compatibility tests of fluid fertilizer-pesticide mixtures conducted May 1970. Fertilizer Solutions. 14(6): 40-46.

Adams, R.S., Jr. 1965. Phosphorus fertilization and the phytotoxicity of simazine. Weed Science. 13: 113-116.

Berg, R.T. and L.W. McElroy. 1953. Effect of 2,4-D on the nitrate content of forage crops and weeds. Can. J. Agr. Sci. 33: 354-358.

Bingham, S.W. and R.P. Upchurch. 1959. Some interactions between nutrient level (N,P,K,Ca) and diuron in the growth of cotton and Italian ryegrass. Weeds. 7: 167-177.

Brady, H.A. 1970. Ammonium nitrate and phosphoric acid increase 2,4,5-T absorption by tree leaves. Weed Science. 18: 204-206.

Bremner, J.M., and D.R. Keeney. 1965. Analytica Chimica Acta. 32: 485-495.

Cooke, A.R. 1957. Influence of 2,4-D on the uptake of minerals from the soil. Weeds. 5: 25-28.

DeVries, M.L. 1963. The effect of simazine on Monterey pine and corn as influenced by lime, bases, and aluminum sulfate. Weeds. 11: 220-222.

Dhillon, P.S., W.R. Byrnes, and C. Merritt. 1967. Simazine and phosphorus interactions in red pine seedlings. Weeds. 15: 339-343.

Doll, J.D. 1969. The influence of nutrient level and combination on herbicide uptake and phytotoxicity. Ph.D. Thesis. Michigan State University, East Lansing.

Doll, J.D., and W.F. Meggitt. 1968. Atrazine and the nitrate content of corn. Agron. J. 60: 655-657.

Doll, J.D., D. Penner, and W.F. Meggitt. 1970. Herbicide and phosphorus influence root absorption of amiben and atrazine. Weed Science. 18: 357-359.

Eastin, E.F., and D.E. Davis. 1967. Effects of atrazine and hydroxyatrazine on nitrogen metabolism of selected species. Weeds. 15: 272-274.

Fink, R.J., and O.H. Fletchall. 1967. The influence of atrazine or simazine on forage yield and nitrogen components of corn. Weeds. 15: 272-274.

Fullilove, H.M. III. 1968. Herbicide and fertilizer combination found to lower yields. Crops & Soils. 20(7): 29.

Furtick, W.R. 1968. A look at liquid fertilizer-herbicide-pesticide mixtures. Fertilizer Solutions. 12(3): 22-24.

Gramlich, J.V., and D.E. Davis. 1967. Effect of atrazine on nitrogen metabolism of resistant species. Weeds. 15: 157-160.

Jacob, K.D. 1954. Status and problems of fertilizer-pesticide mixtures. J. Agr. Food Chem. 2: 970-976.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J.

King, Gary A. 1970. Handle those fluid fertilizer-pesticide mixtures with care. Fertilizer Solutions. 14(3): 50-54.

Klosterboer, A.D., and C.E. Bardsley. 1968. Assessing compatibility of herbicides and nitrogen solutions. Weed Science. 16: 468-470.

Loustalot, A.J., M.P. Morris, J. Garcia, and C. Pagan. 1953. 2,4-D affects phosphorus metabolism. Science. 118: 627-628.

McReynolds, W.D., Jr., and J.A. Tweedy. 1970. Effect of nitrogen form on simazine accumulation in corn, soybeans, and rye. Weed Science. 18: 270-272.

Minshall, W.H. 1969. Effect of nitrogen materials on the uptake of triazine herbicides. Weed Science. 17: 197-201.

Mortvedt, J.J., E.C. Sample, and P.M. Giordano. 1969. Crop response to phosphorus in fluid fertilizers containing pesticides. Fertilizer Solutions. 15(3): 60-64.

Murphy, D.R. 1971. Pesticide/fertilizer combinations - why they'll continue to grow. Fertilizer Solutions. 15(6): 92-96.

Nashed, R.B., and R.D. Ilnicki. 1968. The effect of linuron on ion uptake in corn, soybean, and crabgrass. Weed Science. 16: 188-192.

Petty, H.B., O.V. Burnside, and J.P. Bryant. 1971. Fertilizer combinations with herbicides or insecticides. p. 495-515. In R.A. Olson, T.J. Army, J.J. Hanway, and V.J. Kilmer (ed.). Fertilizer Technology and Use. Soil Sci. Soc. Amer., Madison, Wis.

Rebstock, T.L., C.L. Hamner, and H.M. Sell. 1954. The influence of 2,4-dichlorophenoxyacetic acid on the phosphorus metabolism of cranberry plants (Phaseolus vulgaris). Plant Physiol. 29: 490-491.

Ries, S.K., H. Chimiel, D.R. Dilley, and P. Filner. 1967. The increase in nitrate reductase activity and protein content of plants treated with simazine. Proc. National Acad. Sci. 58:526-532.

Ries, S.K., and A. Gast. 1965. The effect of simazine on nitrogenous components of corn. Weeds. 13: 272-273.

Ries, S.K., R.P. Larsen, and A.L. Kenworty. 1963. The apparent influence of simazine on nitrogen nutrition of peach and apple trees. Weeds. 11: 270-273.

Sabbe, W.A. 1967. Effect of trifluralin on uptake of fertilizer phosphorus. Ark. Farm Research. 16(6): 4.

Schneider, E.C., W.C. Moye, and W. Kincannon. 1969. Herbicides-pesticides-additives and fluid fertilizers. Fertilizer Solutions. 13(3): 28-40.

Selman, F.L., and R.P. Upchurch. 1970. Regulation of amitrole and diuron toxicity by phosphorus. Weed Science. 18: 619-623.

Stahler, L.M., and E.I. Whitehead. 1950. The effect of 2,4-D on nitrate levels in sugar beets. Science. 112: 749-751.

Swanson, C.R., and W.C. Shaw. 1954. The effect of 2,4-dichlorophenoxyacetic acid on the hydrocyanic acid and nitrate content of sudan grass. Agron. J. 46: 418-421.

Upchurch, R.P., G.R. Ledbetter, and F.L. Selman. 1963. The interaction of phosphorus with the phytotoxicity of soil applied herbicides. Weeds. 11: 36-41.

Vega, M.P. 1964. The influence of phosphate on the phytotoxicity of 3-amino-1,2,4, triazole. Diss. Abstr. 25: 82.

Wildon, C.E., C.L. Hamner, and S.T. Bass. 1957. The effect of 2,4-dichlorophenoxyacetic acid on the accumulation of mineral elements in tobacco plants. Plant Physiol. 32: 243-244.

Wort, D.J. 1963. The application of sublethal concentrations of 2,4-D in combination with mineral nutrients. World Rev. of Pest Control. 1: 6-19.

VITA

The author was born December 7, 1948, son of Mr. and Mrs. Louis Meyer, Jr., at Sabetha, Kansas. High school was completed in 1966 at Bern Rural High School. He then entered Kansas State University where the Bachelor of Science in Agronomy was awarded in 1970. The author joined Kansas State University's Agronomy Staff in October, 1970, and began work on the Master of Science Degree. He is married to the former Cathy Allison of Seneca, Kansas.

The author is presently a member of the American Society of Agronomy, the Soil Science Society of American, and Alpha Zeta.

APPENDIX

Table I. Forage yields and plant nutrient content of corn treated with dual applications of atrazine and suspension fertilizer at the rate of 168 kg/ha N, 25 kg/ha P, 46 kg/ha K, and 3.4 kg/ha atrazine - 1970 Ashland location.

Fertilizer-Herbicide Mix	Method of Application	Forage Yield[a]	Plant Tissue Composition[b] %N[c]	%P	%K
No Treatment	None	9.4	2.74	0.197	2.48
Atrazine Only	Preemergent	14.1	2.89	0.196	2.32
Separate Application	Preplant	14.3	3.26	0.227	2.85
Separate Application	Preemergent	12.6	3.31	0.224	2.81
Field Mix	Preplant	13.4	3.28	0.231	2.79
Field Mix	Preemergent	13.9	3.31	0.200	2.53
20 Day Premix	Preplant	12.6	3.32	0.230	2.68
18 Day Premix	Preemergent	13.9	3.34	0.230	2.91
35 Day Premix	Preplant	12.8	3.32	0.220	2.73
28 Day Premix	Preemergent	13.9	3.24	0.212	2.78
$LSD_{.05}$ Treatment		2.7	0.35	ns	0.29
Mix		ns	ns	ns	ns
Application		ns	ns	ns	ns
Mix X Application		ns	ns	ns	ns

a. Yields are corrected to 70% moisture and expressed in metric tons/ha.
b. First leaf opposite and below ear shoot at tasseling stage.
c. Kjeldahl N without nitrates.

Table II. Forage yields, plant nutrient content, and plant nutrient uptake of corn treated with dual applications of atrazine and suspension fertilizer at the rate of 168 kg/ha N, 25 kg/ha P, 46 kg/ha K, and 3.4 kg/ha atrazine - 1970 Manhattan location.

Fertilizer-Herbicide Mix	Method of Application	Forage Yield[a]	Plant Nutrient Composition						Plant Nutrient Uptake[e] kg/ha		
			%N[b]		%P		%K				
			July[c]	Sept[d]	July	Sept	July	Sept	N	P	K
No Treatment	None	28.5	3.17	1.02	0.136	0.116	1.52	0.942	87	9.8	78.3
Atrazine Only	Preemergent	29.6	3.31	1.01	0.154	0.115	1.81	0.831	90	10.3	73.6
Separate Application	Preplant	32.7	3.38	1.05	0.173	0.118	1.78	0.967	103	11.5	94.9
Separate Application	Preemergent	33.9	3.16	1.20	0.166	0.119	1.69	0.781	122	12.1	79.6
Field Mix	Preplant	34.3	3.27	1.20	0.175	0.121	1.45	0.930	124	12.4	95.6
Field Mix	Preemergent	33.9	3.43	1.22	0.169	0.125	1.66	0.856	124	12.8	86.9
25 Day Premix	Preplant	30.0	3.33	1.15	0.176	0.124	1.60	0.905	104	11.2	80.9
18 Day Premix	Preemergent	38.8	3.34	1.24	0.143	0.115	1.59	0.905	144	13.3	104.6
35 Day Premix	Preplant	28.7	3.27	1.22	0.149	0.130	1.60	0.905	106	11.3	77.3
28 Day Premix	Preemergent	31.4	3.37	1.19	0.162	0.123	1.62	0.843	113	11.6	79.3
$LSD_{.05}$	Treatment	ns	ns	0.14	0.030	ns	ns	ns	25	ns	18.6
	Mix	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	Application	3.4	ns	ns	ns	ns	ns	ns	13	ns	ns
	Mix X Application	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

a. Yields corrected to 70% moisture and expressed in metric tons/ha.
b. Kjeldahl N without nitrates.
c. First leaf opposite and below ear shoot at tasseling stage.
d. Whole plant sample chopped for silage.
e. Nutrient uptake calculated using dry weights of forage.

Table III. Yields, grain protein content, and plant nutrient uptake of corn treated with dual applications of atrazine and suspension fertilizer at the rate of 168 kg/ha N, 25 kg/ha P, 46 kg/ha K, and 3.4 kg/ha atrazine - 1971 Ashland location.

Fertilizer-Herbicide Mix	Method of Application	Forage Yield[a]	Grain Yield[b]	Total Yield[c]	% Protein Grain	Plant Nutrient Uptake[d]		
						N	P	K
No Treatment	None	20.0	5775	25.8	7.19	40.5	14.8	120.4
Atrazine Only	Preemergent	16.6	7720	24.2	7.71	29.6	14.1	130.3
Separate Application	Preplant	19.5	8725	28.2	9.40	58.3	14.4	168.5
Separate Application	Preemergent	24.9	8725	33.6	9.48	61.4	16.4	184.8
Field Mix	Preplant	24.4	9038	33.6	9.15	58.0	13.5	160.6
Field Mix	Preemergent	23.4	8536	31.8	9.50	66.3	18.5	166.5
14 Day Premix	Preplant	23.6	9164	32.7	9.42	66.7	18.6	175.0
14 Day Premix	Preemergent	22.9	8160	31.2	9.58	64.1	15.2	177.1
28 Day Premix	Preplant	24.3	8559	33.0	9.62	63.5	18.3	175.3
28 Day Premix	Preemergent	25.3	8662	34.1	9.08	65.5	17.0	153.4
$LSD_{.05}$ Treatment		5.4	964	5.6	0.30	21.2	ns	22.6
Mix		ns	ns	ns	ns	ns	ns	ns
Application		ns	ns	ns	ns	ns	ns	ns
Mix X Application		ns	ns	ns	ns	ns	ns	ns

a. Yields corrected to 70% moisture and expressed in metric tons/ha.
b. Yields corrected to 12.5% moisture and expressed in kg/ha.
c. Grain plus forage at 70% moisture and expressed in metric tons/ha.
d. Nutrient uptake calculated using dry weights of forage and expressed in kg/ha.

Table IV. Plant nutrient content of corn treated with dual applications of atrazine and suspension fertilizer at the rate of 168 kg/ha N, 25 kg/ha P, 46 kg/ha K, and 3.4 kg/ha atrazine - 1971 Ashland location.

Fertilizer-Herbicide Mix	Method of Application	Plant Tissue Composition								
		%N[a]			%P			%K		
		June[b]	July[c]	Oct[d]	June	July	Oct	June	July	Oct
No Treatment	None	2.14	2.27	0.525	0.301	0.352	0.191	2.55	0.87	1.57
Atrazine Only	Preemergent	2.06	2.26	0.406	0.324	0.348	0.194	2.52	0.98	1.79
Separate Application	Preplant	2.51	2.38	0.681	0.336	0.336	0.170	3.05	1.06	1.99
Separate Application	Preemergent	2.50	2.72	0.608	0.329	0.374	0.163	3.00	0.98	1.83
Field Mix	Preplant	2.08	2.74	0.574	0.309	0.372	0.135	2.72	1.05	1.60
Field Mix	Preemergent	2.40	2.45	0.694	0.311	0.376	0.194	2.78	1.08	1.75
14 Day Premix	Preplant	2.39	2.41	0.678	0.333	0.345	0.190	2.92	1.08	1.83
14 Day Premix	Preemergent	2.52	2.55	0.678	0.338	0.367	0.163	3.13	1.00	1.90
28 Day Premix	Preplant	2.46	2.55	0.643	0.332	0.366	0.186	2.99	0.99	1.77
28 Day Premix	Preemergent	2.50	2.42	0.643	0.332	0.375	0.170	3.07	1.06	1.53
$LSD_{.05}$ Treatment		ns	ns	0.160	ns	ns	ns	ns	0.11	0.28
Mix		ns	ns	ns	ns	ns	ns	ns	ns	ns
Application		ns	ns	ns	ns	ns	ns	ns	ns	0.19
Mix X Application		ns	ns	ns	ns	ns	ns	ns	ns	ns

a. Kjeldahl N without nitrates.
b. First fully extended leaf at eight-leaf stage.
c. First leaf opposite and below ear shoot at tasseling stage.
d. Whole plant sample (excluding grain) chopped for silage.

Table V. Yields, grain protein content, and plant nutrient uptake of corn treated with dual applications of atrazine and suspension fertilizer at the rate of 168 kg/ha N, 25 kg/ha P, 46 kg/ha K, and 3.4 kg/ha atrazine - 1971 Manhattan location.

Fertilizer-Herbicide Mix	Method of Application	Forage Yield[a]	Grain Yield[b]	Total Yield[c]	% Protein Grain	Plant Nutrient Uptake[d] N	P	K
No Treatment	None	22.0	6967	29.1	9.38	57.2	5.38	92.3
Atrazine Only	Preemergent	20.6	7093	27.6	9.50	59.6	6.91	90.2
Separate Application	Preplant	23.4	7281	30.7	10.06	64.1	5.67	103.7
Separate Application	Preemergent	21.7	6716	28.5	9.87	39.1	5.73	80.0
Field Mix	Preplant	26.4	7281	33.8	9.81	53.9	6.26	126.5
Field Mix	Preemergent	22.3	7038	29.4	10.33	64.2	6.49	90.5
14 Day Premix	Preplant	25.0	7155	32.3	9.92	58.4	6.49	84.9
14 Day Premix	Preemergent	20.2	7281	27.6	9.89	49.1	5.10	93.3
28 Day Premix	Preplant	24.9	7155	32.0	10.08	79.1	8.01	104.6
28 Day Premix	Preemergent	23.5	6842	30.5	9.32	40.9	4.16	91.2
$LSD_{.05}$ Treatment		ns	ns	ns	ns	7.6	0.83	14.5
Mix		ns	ns	ns	ns	4.8	ns	9.9
Application		ns	ns	2.2	ns	3.4	0.36	7.0
Mix X Application		ns	ns	ns	ns	6.8	0.59	13.9

a. Yields are at 70% moisture and expressed in metric tons/ha.
b. Yields are at 12.5% moisture and expressed in kg/ha.
c. Grain plus forage at 70% moisture and expressed in kg/ha.
d. Nutrient uptake calculated using dry weights of forage and expressed in kg/ha.

Table VI. Plant nutrient content of corn treated with dual applications of atrazine and suspension fertilizer at the rate of 168 kg/ha N, 25 kg/ha P, 46 kg/ha K, and 3.4 kg/ha atrazine - 1971 Manhattan location.

Fertilizer-Herbicide Mix	Method of Application	Plant Tissue Composition %N[a] June[b]	%N[a] July[c]	%P June	%P July	%K June	%K July
No Treatment	None	2.48	2.42	0.228	0.276	1.73	0.714
Atrazine Only	Preemergent	2.52	2.45	0.231	0.295	1.90	0.771
Separate Application	Preplant	2.53	2.43	0.235	0.308	1.75	0.829
Separate Application	Preemergent	2.49	2.57	0.229	0.281	2.01	0.829
Field Mix	Preplant	2.57	2.42	0.240	0.291	1.85	0.840
Field Mix	Preemergent	2.63	2.57	0.231	0.303	1.83	0.771
14 Day Premix	Preplant	2.54	2.48	0.236	0.296	1.81	0.783
14 Day Premix	Preemergent	2.45	2.51	0.220	0.294	1.94	0.817
28 Day Premix	Preplant	2.54	2.37	0.234	0.290	1.87	0.816
28 Day Premix	Preemergent	2.64	2.37	0.235	0.324	1.85	0.783
$LSD_{.05}$ Treatment		ns	ns	ns	ns	ns	ns
Mix		ns	ns	ns	ns	ns	ns
Application		ns	ns	0.007	ns	ns	ns
Mix X Application		ns	ns	ns	ns	ns	ns

a. Kjeldahl N without nitrates.
b. First fully extended leaf at eight-leaf stage.
c. First leaf opposite and below ear shoot at tasseling stage.

Table VII. Effect of atrazine-suspension fertilizer contact time on growth, nutrient content, and nutrient uptake of corn under controlled conditions - growth chamber study using oats as indicator of phytotoxicity.

Treatment	Dry Weight[a]	Plant Nutrient Content			Plant Nutrient Uptake[b]		
		%N[c]	%P	%K	N	P	K
No Treatment	1.63	1.03	0.169	1.20	16.9	2.75	19.4
Atrazine Only	1.73	1.15	0.175	1.75	19.9	3.02	30.3
Fertilizer Only	2.43	1.82	0.120	1.40	44.4	2.95	33.7
Separate Appl'n.	3.57	2.00	0.154	1.88	70.5	5.48	67.2
1 Hour Premix	3.40	2.23	0.158	1.69	76.0	5.42	57.4
10 Day Premix	3.50	2.40	0.189	2.03	84.6	6.70	71.6
25 Day Premix	3.70	2.21	0.144	1.36	81.7	5.32	50.2
40 Day Premix	3.50	2.31	0.145	1.38	80.8	5.07	48.4
70 Day Premix	3.50	2.31	0.171	1.60	81.1	6.02	55.7
100 Day Premix	3.60	2.31	0.179	1.88	83.3	6.46	67.7
130 Day Premix	3.83	2.26	0.183	1.70	86.6	6.96	64.8
160 Day Premix	3.23	2.05	0.146	1.45	66.3	4.70	46.6
190 Day Premix	3.60	2.46	0.194	1.40	88.4	6.97	50.3
$LSD_{.05}$	0.46	0.37	0.037	0.30	16.4	1.65	11.5

a. Weight in grams/3 plants.
b. Milligrams uptake/3 plants.
c. Kjeldahl N without nitrates.

Table VIII. Effect of atrazine-suspension fertilizer contact time on growth, nutrient content, and nutrient uptake of corn under controlled conditions - growth chamber study using velvetleaf as indicator of phytotoxicity.

Treatment	Dry Weight[a]	Plant Nutrient Content			Plant Nutrient Uptake[b]		
		%N[c]	%P	%K	N	P	K
No Treatment	1.10	1.01	0.232	1.67	11.1	2.56	18.2
Atrazine Only	1.33	1.13	0.236	1.84	15.0	2.49	17.8
Fertilizer Only	1.48	1.80	0.189	1.80	26.8	2.80	26.9
Separate Appl'n.	1.82	1.98	0.201	2.18	36.0	3.66	39.4
1 Hour Premix	1.77	1.90	0.200	1.51	33.5	3.47	26.5
7 Day Premix	1.78	2.08	0.216	1.80	37.1	3.85	32.2
20 Day Premix	1.85	2.02	0.201	1.77	37.3	3.72	32.7
35 Day Premix	1.85	2.12	0.257	2.10	39.2	4.77	38.8
50 Day Premix	1.82	1.93	0.198	1.87	35.0	3.61	34.2
80 Day Premix	1.68	2.13	0.234	2.03	35.8	3.93	34.3
110 Day Premix	1.80	2.01	0.222	2.34	36.2	4.00	42.1
140 Day Premix	1.80	1.91	0.198	1.60	34.4	3.56	28.7
170 Day Premix	1.87	1.84	0.210	2.01	34.4	3.92	37.6
200 Day Premix	1.85	2.02	0.222	1.77	37.2	4.07	33.6
230 Day Premix	1.85	1.94	0.198	1.90	35.8	3.65	35.1
$LSD_{.05}$	0.16	0.22	ns	ns	3.4	0.87	8.9

a. Weight in grams/3 plants.
b. Milligrams uptake/3 plants.
c. Kjeldahl N without nitrates.

Table IX. Effect of alachlor-suspension fertilizer contact time on growth, nutrient content, and nutrient uptake of corn under controlled conditions.

Treatment	Dry Weight[a]	Plant Nutrient Content			Plant Nutrient Uptake[b]		
		%N[c]	%P	%K	N	P	K
Fertilizer Only	3.02	1.54	0.185	3.49	46.3	5.58	105.1
Separate Appl'n.	2.73	1.84	0.158	3.28	50.2	4.31	89.6
1 Hour Premix	2.82	1.85	0.169	3.35	52.1	4.78	94.2
25 Day Premix	2.79	1.79	0.166	3.50	49.9	4.63	97.7
50 Day Premix	2.85	1.88	0.173	3.25	53.6	4.96	92.7
100 Day Premix	2.93	1.72	0.196	3.37	50.3	5.76	98.5
$LSD_{.05}$	ns	0.20	ns	ns	ns	ns	ns

a. Weight in grams/3 plants.
b. Milligrams uptake/3 plants.
c. Kjeldahl N without nitrates.

Table X. Effect of alachlor/atrazine-suspension fertilizer contact time on growth, nutrient content, and nutrient uptake of corn under controlled conditions.

Treatment	Dry Weight[a]	Plant Nutrient Content			Plant Nutrient Uptake[b]		
		%N[c]	%P	%K	N	P	K
Fertilizer Only	3.05	1.47	0.180	3.25	44.8	5.48	99.1
Separate Appl'n.	2.88	1.03	0.146	2.98	29.7	4.23	57.8
1 Hour Premix	2.89	1.32	0.138	2.39	37.7	4.00	68.5
25 Day Premix	2.71	1.67	0.157	3.15	44.3	4.21	83.9
50 Day Premix	2.92	1.36	0.148	2.81	38.6	4.28	80.2
100 Day Premix	2.93	1.39	0.148	2.78	41.1	4.35	82.2
$LSD_{.05}$	ns	ns	ns	ns	ns	ns	ns

a. Weight in grams/3 plants.
b. Milligrams uptake/3 plants.
c. Kjeldahl N without nitrates.

Table XI. Effect of butylate-suspension fertilizer contact time on growth, nutrient content, and nutrient uptake of corn under controlled conditions.

Treatment	Dry Weight[a]	Plant Nutrient Content			Plant Nutrient Uptake[b]		
		%N[c]	%P	%K	N	P	K
Fertilizer Only	2.89	1.55	0.218	3.79	44.9	6.29	106
Separate Appl'n.	3.16	1.71	0.230	4.05	54.0	7.27	128
1 Hour Premix	3.22	1.83	0.242	4.06	58.3	7.74	130
25 Day Premix	3.44	1.73	0.212	3.63	59.5	7.29	125
50 Day Premix	3.33	1.62	0.207	3.09	53.6	6.82	101
100 Day Premix	3.39	1.55	0.214	3.48	52.5	7.25	118
$LSD_{.05}$	ns	ns	ns	0.62	ns	ns	17

a. Weight in grams/3 plants.
b. Milligrams uptake/3 plants.
c. Kjeldahl N without nitrates.

Table XII. Effect of trifluralin-suspension fertilizer contact time on growth, nutrient content, and nutrient uptake of soybeans under controlled conditions.

Treatment	Dry Weight[a]	Plant Nutrient Content			Plant Nutrient Uptake[b]		
		%N[c]	%P	%K	N	P	K
Fertilizer Only	1.53	1.39	0.156	1.69	21.3	2.38	25.9
Separate Appl'n.	2.50	1.11	0.145	1.27	27.4	3.59	31.3
1 Hour Premix	2.53	1.35	0.145	1.54	33.9	3.66	38.9
25 Day Premix	2.53	1.22	0.141	1.45	34.1	3.93	40.5
50 Day Premix	2.55	1.32	0.143	1.41	33.9	3.65	36.3
100 Day Premix	2.57	1.28	0.154	1.49	32.7	3.95	38.3
$LSD_{.05}$	0.55	ns	ns	ns	7.7	0.87	ns

a. Weight in grams/3 plants.
b. Milligrams uptake/3 plants.
c. Kjeldahl N without nitrates.

Table XIII. Effect of norea/atrazine-suspension fertilizer contact time on growth, nutrient content, and nutrient uptake of grain sorghum under controlled conditions.

Treatment	Dry Weight[a]	Plant Nutrient Content			Plant Nutrient Uptake[b]		
		%N[c]	%P	%K	N	P	K
Fertilizer Only	2.93	1.09	0.137	2.13	31.6	4.00	62.2
Separate Appl'n.	2.44	2.16	0.209	3.11	52.9	5.10	76.2
1 Hour Premix	2.28	2.43	0.220	3.53	55.2	5.02	80.4
25 Day Premix	2.13	2.67	0.245	3.55	56.4	5.15	75.7
50 Day Premix	2.53	1.60	0.142	2.52	40.8	3.59	63.7
100 Day Premix	2.23	2.12	0.221	3.16	47.1	4.91	70.4
$LSD_{.05}$	0.39	0.69	0.037	0.91	12.9	0.70	ns

a. Weight in grams/3 plants.
b. Milligrams uptake/3 plants.
c. Kjeldahl N without nitrates.

PHYSICAL AND CHEMICAL COMPATIBILITY OF HERBICIDE-SUSPENSION FERTILIZER COMBINATIONS

by

LOUIS JON MEYER

B.S., Kansas State University, 1970

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

The compatibility of 2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine (atrazine) in a suspension fertilizer containing 15% N, 6.5% P, and 12.5% K was studied in four field and two growth chamber investigations. In the field, preplant incorporated applications were compared to preemergent applications of the combined materials; separate applications were compared to mixes made immediately prior to application, 14 day premixes, and 28 day premixes. Effectiveness of the combined materials after being in contact with each other for extended periods of time was studied under controlled conditions in the growth chamber.

Five other classes of herbicides (a thiocarbamate, an amide, a thiocarbamate/triazine, a norea/triazine, and an aniline) were combined with the same suspension fertilizer to evaluate the effect of extended fertilizer-herbicide contact time in the growth chamber. Plant nutrient uptake and vegetative yields were used to evaluate fertilizer effectiveness, visual and pictorial comparisons were used to evaluate herbicide phytotoxicity. Physical compatibility determinations were made on all mixtures used.

All combined materials were both physically and chemically compatible, and all herbicides were as effective when applied in combination with the fertilizer as when applied separately. All herbicides studied can be mixed with the suspension fertilizer prior to application and remain effective during the current growing season.

Preplant incorporated applications displayed greater fertilizer response under dryland field conditions due to better positional availability of applied nutrients. Preemergent applications produced greater atrazine phytotoxicity under dryland conditions. These results indicate increased herbicide rates may be needed when preplant applications are used to offset the diluting effect of incorporation. No differences in atrazine or fertilizer effectiveness due to method of application were noted under irrigated field conditions.