

THE IMPACT OF K FERTILIZATION ON GRAIN YIELD
OF WINTER WHEAT, ON BUILDUP OF
EXCHANGEABLE K, AND ON SOIL
SOLUTION COMPOSITION

By

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CHAPTER I

INTRODUCTION

Potassium is taken up in greater quantities than any other element with the exception of nitrogen. The immediate source from which uptake occurs is only a fraction of the total potassium in the soil. Total potassium in the soil is comprised of primary minerals (unavailable to plants), secondary minerals (slowly available to plants), and K ions located on the exchange complex and in the soil solution (readily available to plants).

Soils of western Oklahoma have higher exchangeable K levels than soils of central and eastern Oklahoma. In some counties of eastern Oklahoma, exchangeable K levels are insufficient to adequately supply K requirements for winter wheat production (16). Soil test indices of exchangeable K levels at the Eastern Research Station at Haskell in Muskogee county indicate that such a condition exists. Maximum production would then be expected upon additions of a K fertilizer source; however, this was not the case.

A comprehensive examination of the soil profile and soil solution was undertaken to establish a reasonable explanation for the lack of potassium response.

CHAPTER 11

ABSTRACT

Exchangeable K is the criterion on which the fertility status of available soil K is based. The amount of exchangeable K of several eastern Oklahoma soils is considered to be inadequate to sufficiently meet the needs of several crops including winter wheat (*Triticum aestivum* L.). The objective of this research project was to determine the effects of K fertilization on grain yield response and uptake of N, P, and K by winter wheat, the buildup of exchangeable K, and the influence on the soil solution composition. This study was initiated in the fall of 1977 on a Taloika silt loam (Mollic albaqualfs) and completed in 1983. Fertilizer rates consisted of fixed rates of N (112 kg ha^{-1}) and P (49 kg ha^{-1}) applied to all treatments ensuring against deficiencies, and six rates of K (0, 56, 112, 224, 560, 1120 kg ha^{-1}). All fertilizers were applied in the fall of 1977, 1978, and 1979.

There was not an effect on means of grain yield and nutrient uptake over a six-year period due to K fertilization. Applications of K fertilizer had little effect on the buildup of exchangeable K at rates of 56, 112, and 224 kg K ha^{-1} in comparison to the control. Significant increases in exchangeable K, K concentration of the soil solution, and K ion activity were observed at K rates of 560 and 1120 kg ha^{-1} in comparison to rates of 0, 56, 112, and 224 kg ha^{-1} . Significant increases in exchangeable K at rates of 560 and 1120 kg ha^{-1} were also observed to a

depth of 31 cm. There was a significant decrease in exchangeable K in the soil profile of the control group at a depth of 31 to 62 cm when compared to exchangeable K at 0 to 15 cm and 92 to 123 cm. Surface samples of the control group did not differ significantly in exchangeable K throughout the six years of the experiment, indicating that the topsoil has the ability to recharge the exchange complex with K from an undetermined source.

The impact of K fertilization on soil solution composition was negligible except for aluminum. Significant increase in Al^{3+} , AlSO_4 , and AlOH concentration occurred at the $1120 \text{ kg K ha}^{-1}$. Increases in Al^{3+} ion activity and Al^{3+} ion concentration were correlated with increases in K rates, suggesting that displacement of Al into the soil solution is caused by K fertilization. Potentially hazardous levels of Al^{3+} exist in the soil solution at K rates of 560 and 1120 kg ha^{-1} as determined by Al ion activity values.

CHAPTER III

LITERATURE REVIEW

Exchangeable K has long been used in determining the fertility status of soil K. In most cases this is perfectly acceptable; however, situations arise where exchangeable K is not always a reliable estimate of the fertility status of soil K. A case in point is a negative response of sunflower seed yields and a poor response of white clover to exchangeable K (13, 19) in contrast to positive correlations, associating soil solution K concentration to yield response of these respective crops.

The inability of exchangeable K to accurately represent the fertility status of soil potassium may lie in the soil physical properties such as the presence of highly structured clays (2:1) which trap and fix K on interlattice adsorption sites (30).

The interlayer adsorption sites present in 2:1 clays are highly specific for K (8). Release of K from selective sites occurs through the exchange process of film diffusion (10) with similar sized ions (i.e., NH_4^+) or in the case of H through proton of hydrogen bond transfer (30).

The dynamics of the K ion in the soil is controlled to a large extent by K in solution and its contact with clay minerals (21). As K fertilizer is added to the soil, the soil solution K concentration increases, causing a shift in the equilibrium reaction (nonexchangeable K \rightleftharpoons exchangeable K \rightleftharpoons water soluble K) toward fixation (36). The exchange sites located on the planar surfaces and lattice edges equilibrate rapidly with

the soil solution. Movement from exchangeable sites to nonexchangeable sites proceeds much slower depending on the presence and selectivity of interlayer sites (22, 29). Potassium diffusion into the interlayer zone proceeds very slowly (diffusion coefficient of 10^{-17} to 10^{-23} $\text{cm}^{-2} \text{sec}^{-1}$) (22) continuing over an extended period of time (21).

Movement of K into the structure collapses the lattice trapping the K (29). Once K is adsorbed in these interlattice sites, it cannot be removed by methods measuring exchangeable K. Desorption of fixed K from interlattice sites is a slow process (diffusion coefficient of 3×10^{-19} $\text{cm}^2 \text{sec}^{-1}$) (32, 35), whereas external planar sites and edge-layer sites are rapidly desorbed (10, 32).

Release of nonexchangeable K can be influenced by soil pH and temperature. As temperature increases or pH decreases to acidic levels, nonexchangeable K is released (7, 12, 15, 23, 30). The effect of acidic conditions on release of nonexchangeable K can be explained by solubilization of Al forming polymers such as Al(OH) which are capable of competing for interlayer sites (23), by the exchange with H^+ ions, and by the formation of interlayer hydroxy-Al and Fe wedges preventing the collapse of the lattice (31). Release of nonexchangeable K by H^+ ions under acidic conditions is supported by research using an H^+ saturated resin which shows a linear increase in nonexchangeable K release with increasing H^+ concentration. The amount of K released was limited to the amount of H^+ ions in the system (15).

The movement of ions from soil particles into solution is vital to plant maintenance and growth. This fraction of nutrients more accurately represents the chemical environment of roots than nutrients obtained through soil extractants (3, 27). The soil solution concept represents

plant nutrient availability to plants as demonstrated by ionic activities and their relationship on root growth in culture and in soil solutions (2, 3, 4, 17, 27). Although positive correlations are seen between ion activity and inhibited plant and root growth, some concern exists by expressing ion concentration as activities due to strict thermodynamic definitions (5, 33) and lack of a general procedure relating activities of charge species to macroscopic properties without employing unmeasurable parameters (14). Nevertheless, the importance of ion activities and its influence on plant and root development is shown in a study on cotton seedling root growth in culture and soil solution in which the only consistent parameter correlated with root growth restriction was molar activity of Al^{3+} (4) (parameters measured consisted of exchangeable Al, solution Al, and molar activity of Al). Research of Al toxicity on coffee plants (*Coffea arabica* L.), corn, sorghum, and *Griminea* species indicates that Al ion activity is correlated with plant and root growth reductions (25, 26). Earlier research on NH_3 toxicity clearly demonstrates the importance of ion activities. Seedling injury and death were attributed to NH_3 toxicity from $(NH_4)_2 HPO_4$ fertilizer, when in effect damage was actually the result of a Ca induced deficiency caused by the precipitation of exchangeable and solution Ca by the soluble phosphate (1, 9).

The objectives of this study were to measure the impact of increasing K fertilizer rates on exchangeable K levels, soil solution composition, and grain production of winter wheat (*Triticum aestivum* L.).

CHAPTER IV

MATERIALS AND METHODS

This project was initiated on a Taloka silt loam (Mollic albaqualfs) at the Eastern Research Station in Haskell, Oklahoma. The study was designed as a randomized complete block composed of four replications and six rates of K (0, 56, 112, 224, 560, and 1120 kg ha⁻¹). Fixed rates of N and P (112 and 49 kg ha⁻¹, respectively) were applied to ensure that sufficient amounts met normal crop production requirements. Fertilizers were applied in the fall of 1977, 1978, and 1979 prior to planting winter wheat (*Triticum aestivum* L. "Tam W 101"). Fertilizer sources included ammonium nitrate (34-0-0), triple superphosphate (0-46-0), and muriate of potash (0-0-62). Grain weights and yields were determined after harvesting a 3 x 15 m strip in a 6 x 15 m plot. Soil samples of the plow layer taken annually for six years were analyzed for N, P, K, pH, and Buffer Index at the Oklahoma State University Soil Testing Laboratory. Values of soil properties at the respective rates of K are listed in Table I.

A detailed sampling of the soil profile was performed in July of 1983. Three core samples were taken in each plot to a depth of 123 cm. These core samples were broken down by increments of 0 to 15, 15 to 31, 31 to 62, 62 to 92, and 92 to 123 cm into individual samples. Samples were oven dried at 60 C prior to chemical analyses. Chemical analysis of the soil samples from the profile include pH, determined by a glass electrode; Ca, Mg, Na, and K by atomic absorption spectroscopy; NO₃⁻-N

and NH_4^+ -N using a Technicon Auto Analyzer; and P using Bray and Kurtz No. 1 (1:20) P extraction method. CEC was determined by a modification of the Bower et al. method (1952) and was restricted to control plots of each replication.

Samples for soil solution analysis were taken in 1983 following harvest. These samples were air dried, sieved using a 5-10 mesh screen, moistened and placed into a glass column (5 x 60 cm) to a depth of 44 cm. The soil in the column (600 g) was wetted to field capacity and allowed to equilibrate for 24 hours. The soil solution of the soil column was then displaced with a saturated solution of CaSO_4 containing a Thiocyanate indicator ($4 \text{ g KCNS } \ell^{-1}$). The pH of the solution was monitored every two hours during sample collection. The final collected sample was centrifuged in a refrigerated centrifuge at 10000 rpm for 10 minutes to remove suspended material and cooled at 5 C until chemical analysis was performed. To prevent microbial alteration, two drops of Toluene were added to each sample. Chemical analysis performed on the displaced solution included NH_4^+ -N and NO_3^- -N using micro-Kjeldahl (Bremner, 1965); P was determined colorimetrically (Murphy and Riley, 1963); SO_4 was determined turbidimetrically (Bardsley and Lancaster, 1960); CO_3 and HCO_3 were determined using phenolphthalein and methyl orange as end point indicators (Bower, 1965); Cl was determined by titration with AgNO_3 (Bower, 1965); K, Ca, Na, and Mg were determined by atomic absorption spectroscopy with air acetylene flame; and Al was determined by atomic absorption spectroscopy using nitrous oxide. Data reported for solution analysis are the means of duplicate displacements.

Two computer programs were used in computing free ion and ion pair concentration; one was the Adams (3) procedure of successive iterations

and approximations, and the second was the GEOCHEM procedure (34). Values for both systems are listed in Appendix A. GEOCHEM data of ion and ion-pair concentration will be used for statistical analysis of soil solution and for computation of ion activity using the Davies equation. Statistical analysis of all data was performed by SAS using a critical value of 0.05 to test for levels of significance.

CHAPTER V

RESULTS AND DISCUSSION

Effects of K Rates on Grain Yield

Response and Nutrient Uptake

Bray's percent sufficiency concept has been incorporated into the soil test recommendations at Oklahoma State University. Based on this concept, one can expect a yield of 80 percent of normal (the yield possibility) due to a limiting amount of K shown in Table I under the control group (0 kg ha^{-1}). Normal yields could be expected if K levels were 280 kg ha^{-1} .

In the initial and final years of the study (1978 and 1983), significant decreases in yield occurred with increasing rates of K. These results were offset by significant increases in grain yield in 1980, 1981, and 1982 in response to increasing K rates. In 1979, no substantial difference in grain yield was recorded. The effects of K fertilization on grain yield in individual years and the mean over six years are shown in Figures 1 and 2, respectively. Significant increases in grain yield or in N, P, and K uptake did not occur with increasing rates of K. Nutrient concentration response to applied K is shown in Figure 3.

Influence of K Rates on Exchangeable K

The greatest single response to K fertilization was the immediate significant buildup of exchangeable K with rates of 560 and 1120 kg K

ha^{-1} that was present at the end of the initial year and during subsequent years of the study (Figure 4). Potassium fertilization in second and third years of application significantly increased exchangeable K with rates of 112 and 224 kg ha^{-1} over that observed with 0 kg K ha^{-1} . Upon termination of K applications in 1980, significant differences in exchangeable K between lower rates dissipated (Figure 4) (1981 data).

The exchangeable K of the control group did not differ significantly during the six years of the experiment (Figure 5). Total uptake of K in grain through the duration of the study equates to approximately 56 kg ha^{-1} . The greatest change in exchangeable K levels of the control groups occurred between 1979 and 1980, with the difference being a net decrease of 58 kg ha^{-1} of K in 1980. The difference in exchangeable K from the first year of the experiment (1978) to the last year of the experiment (1983) was only 7 kg ha^{-1} (Figure 5). The total range of exchangeable K in the control group excluding 1979 data amounts to only 18 kg ha^{-1} of K. This suggests that reserves of nonexchangeable K exist in the soil, equilibrating to an exchangeable form upon depletion of exchangeable K, but prior to this equilibration cannot be accounted for by NH_4OAc extraction.

Exchangeable K in the Soil Profile

An investigation of exchangeable K in the soil profile was conducted to determine if wheat plants were extracting their K requirements from subsurface K. Determination of exchangeable K with depth in the soil profile showed a decrease of exchangeable K until 62 cm, at which point K increased. This decrease can be explained by extraction of K by plant roots at subsurface levels and translocation of K to the vegetative parts

of the plant. Potassium is recycled to the soil surface upon plant decomposition, but the immobility of K in the soil restricts it from replenishing the subsurface horizons. The exchangeable K at 31 to 62 cm is significantly lower than the exchangeable K at 0 to 15 and 92 to 123 cm (Figure 6). Exchangeable K at 0 to 15 cm is not significantly different from K levels at 15 to 31 or at 62 to 123 cm. The greatest concentration of exchangeable K occurs at 93 to 123 cm and is significantly higher than all other depths sampled except the surface soil (0 to 15 cm).

Statistically higher levels of exchangeable K at rates of 560 and 1120 kg K ha⁻¹ are shown to a depth of 31 cm, suggesting that saturation of exchange sites has occurred and excess K has moved with the water front deeper into the soil (Figure 7). High levels of exchangeable K at the rate of 1120 kg K ha⁻¹ continue to exist with depth of the soil but were not significantly different than levels at the other rates (Figure 7).

Soil Solution and Ion Activity

The speciation equilibrium model GEOCHEM (34) is the most widely accepted program used for determining the ionic strength and concentration of cations, anions, and ion-pairs in the soil solution (6). From this information one can easily calculate ion activities which can then be related to plant growth. An accurate analysis of the soil solution should include the metals and ligands listed in Table II. However, a satisfactory evaluation of the solution can be accomplished analyzing the metals, ligands, and pH listed in Table III.

The effect of K fertilization on major cations and anions in the soil solution was negligible except for K and Al species. Significant

increases of solution K concentration occurred with applications of 560 and 1120 kg K ha⁻¹ in comparison to the other rates. The influence of K fertilization on K concentration in the soil solution is identical to K fertilization's effect on exchangeable K. The additional K applied at rates of 56, 112, and 224 kg ha⁻¹ in 1977, 1978, and 1979 cannot be accounted for in grain uptake, in exchangeable K, or in solution concentration, which indicates that K was most likely fixed by the soil. This supports an earlier statement indicating that this particular soil has the ability to retain K in a nonexchangeable form. Significantly higher levels of solution and exchangeable K at K rates of 560 and 1120 kg ha⁻¹ four years after fertilizer application suggests that K equilibrium between the soil solution, exchange sites, and nonexchangeable sites has been established. Higher K concentrations in the soil solution at 560 and 1120 kg K ha⁻¹ application rates were susceptible to water movement, though significant increase in exchangeable K was not found at a depth greater than 31 cm.

The application of K fertilizer to an acid soil can result in the displacement of Al from the exchange complex into solution, inhibiting plant root development (28). A similar pattern of Al displacement by KCl applications exists in this study. This is substantiated by a linear correlation of Al³⁺ ion concentration to increasing rates of K ($r=0.58$). The applications of excessive amounts of K resulted in significant increases in Al³⁺ ion concentration as shown by comparison of the 1120 kg K ha⁻¹ rate to the control and 56 kg K ha⁻¹ rate. This significant increase of Al³⁺ with 1120 kg K ha⁻¹ parallels significant increases of Al ion-pairs, AlOH and AlSO₄ at 1120 kg K ha⁻¹ over the 0 kg K ha⁻¹ rate (Figure 8). Percentages of Al³⁺ and Al ion-pairs by rates are shown in

Table IV. Percentages of AlCO_3 and AlCl_3 were less than 1 percent and are not shown.

The detrimental effects of Al^{3+} concentration of soil solution on plant growth has been documented by critical concentration levels. This critical concentration will vary with soil characteristics and plant species (4, 28). A parameter consistent in associating Al toxicity to growth response of cotton seedlings (4), coffee seedlings (26), sorghum and corn seedlings (11) is the ionic activity of Al^{3+} . The critical activity level of Al^{3+} ion for the species listed above ranges from 2 μM to 12 μM . The range of Al^{3+} ion activity of this study is listed in Figure 9 and falls within the range shown to be harmful to the species listed above. The Al^{3+} ion activity correlates with increasing K rates ($r=0.53$), with significant increases in activity occurring at 1120 kg K ha⁻¹. Little if any work has been completed concerning Al^{3+} activity threshold levels on wheat seedlings, restricting one from making a direct statement of Al^{3+} ion activity on winter wheat in this study.

Computer Models and Speciation of Metal and Ligand Concentration

A large number of computer packages are available for calculating free metal and ligand concentration from which single ion activities can be calculated, causing some variation between these programs. In a comparison of 14 computer programs, one researcher found major and minor differences in speciation concentration of metals and ligands (24). Discrepancies of speciation concentration between models can be attributed to one or more of the following:

1. Failure to include all species in the mass balance equation (5).

2. Number of routines used in calculating ionic strength and ion concentration (6).

3. Inappropriate formation constant used (5, 24).

4. Manner in which activity corrections are computed (6).

Electroneutrality is not required by most programs (6, 24) and a successful computation can be accomplished (18) without its consideration. Caution must be exercised since total moles of positive and negative components are not necessarily equal, and in some cases the solution can be electrically unbalanced by as much as 25 percent (6, p. 527): "Results from such a data set should be reviewed with care knowing that the problem has been incompletely specified due to analytical errors or omission or that the thermodynamic data may need careful review."

Comparison of the GEOCHEM and Adams Models

Several models exist for determining metal and ligand concentrations of the soil solution, two of which have been employed for use in this study: GEOCHEM (34) and Adam's model of successive iterations and approximations (3).

Lack of significant correlation coefficients between respective ions and ion-pairs comparison by a correlation matrix of GEOCHEM and Adams can be attributed to those factors listed earlier in the section concerning speciation of metal and ligand concentrations in computer modeling.

Results of the correlation matrix indicate a highly significant association between K ion concentrations of GEOCHEM and Adams with a correlation coefficient of 0.99, and between AlOH ion-pair concentrations with a correlation coefficient of 0.97. Additional significant correlations occurring between species include Mg, NH_4^+ , NO_3^- , and KSO_4^- . Correlation

among ions or ion-pairs of Ca^{2+} , Al^{3+} , SO_4 , MgSO_4 , and AlSO_4 did not occur. All elements included in the correlation matrix and their correlation coefficients are listed in Table V.

CHAPTER VI

CONCLUSION.

Potassium fertilization significantly increased levels of exchangeable K, soil solution K, and K ion activity at fertilizer rates of 560 and 1120 kg K ha⁻¹. Grain yield and nutrient uptake did not respond to K fertilization. The lack of grain yield response to K fertilization can be attributed to inherent characteristics of the soil releasing K from a mineral source supplying plants with enough available K to meet their physiological requirements. A relatively constant level of exchangeable K in the control group throughout the six years of the experiment would support the concept of the soil being a greater reservoir of K than originally thought.

The impact of K treatments on soil solution composition was minimal except for the Al species of Al³⁺, AlOH, and AlSO₄. Each of these species exhibited significant increases in concentration levels at 1120 kg ha⁻¹ of applied K. The ion concentration and ion activity of Al³⁺ and K were correlated to rates of K applied.

The effect of Al³⁺ activity on wheat plants appears to be minimal at this time. Threshold levels of Al³⁺ ion activity on wheat seedlings must first be established before any kind of statement can be made concerning toxicity levels.

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APPENDIX A

TABLES

TABLE I

SOIL TEST INDICES IN THE SURFACE SOIL (0 TO 15 CM) AFTER THREE ANNUAL FERTILIZATIONS WITH K AND SIX CROPPING YEARS TO WINTER WHEAT

K Rate	pH	NO_3^- -N	NH_4^+ -N	P	K	Ca	Mg	Na	C.E.C.
kg ha^{-1}		kg ha^{-1}						$\text{mmole}(\text{Na}^+)\text{kg}^{-1}$	
0	5.5	60	235	55	146	1155	193	84	13
56	5.5	61	268	46	186	1241	209	91	---
112	5.4	60	210	46	210	1257	224	87	---
224	5.4	55	262	49	229	1215	203	83	---
560	5.3	66	235	62	395	1245	174	93	---
1120	5.3	76	252	56	660	1031	132	75	---

TABLE II

A TYPICAL CHECKLIST FOR METALS AND LIGANDS TO BE INCLUDED IN THE DATA FOR A GEOCHEMICAL MODEL

Metals	Ligands
H, Na, Ca	Inorganic C, S, P as
Mg, K, Mn	CO_3^{2-} , SO_4^{2-} and PO_4^{3-}
Al, Fe, Cu	NO_3^- , NH_3 (NH_4^+), F
An, Ni, Cd	Cl, Si, Organic C (CTS)
Cr	

Input values for the metal and ligand components are entered as total analytical concentrations (Baham, 1984).

TABLE III

MINIMUM REQUIREMENTS FOR METAL AND LIGAND SPECIATION DETERMINATIONS USING GEOCHEM MODEL

Metals	Ligands
$\text{Ca}_{(T)}$	$\text{CO}_3_{(T)}$
$\text{Mg}_{(T)}$	$\text{SO}_4_{(T)}$
$\text{K}_{(T)}$	$\text{Cl}_{(T)}$
$\text{Na}_{(T)}$	
pH	

$\text{CO}_3^* = \{\text{CO}_3^{2-}\} + \{\text{HCO}_3^-\} + \{\text{H}_2\text{CO}_3\}$, where { } refers to a molar concentration (Sposito and Matigod, 1980).

TABLE IV
EFFECT OF K FERTILIZATION ON ALUMINUM SPECIES IN THE
SURFACE SOIL (0 TO 15 CM) OF A TALOKA SILT LOAM

K Rates	Al^{3+}	$AlSO_4$	$AlOH$
$kg\ ha^{-1}$	Mole Fraction, %		
0	3.1	1.4	95.4
56	4.9	1.0	94.0
112	5.5	1.8	92.4
224	5.9	2.0	92.0
560	9.4	2.1	88.1
1120	7.4	2.7	89.4

TABLE V
CORRELATION BETWEEN IONIC SPECIES
OF GEOCHEM AND ADAMS
EQUILIBRIUM MODELS

Species	(r)
Ca ⁺⁺	0.33
CaSO ₄	0.40
Mg ⁺⁺	0.57*
K ⁺	0.99**
KSO ₄ ⁻	0.99*
Al ₃ ⁺	0.32
AlSO ₄	0.40
AlOH	0.97**
SO ₄ ⁼	0.25
NH ₄ ⁺	0.44*
NO ₃ ⁻	0.69*

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

APPENDIX B

FIGURES

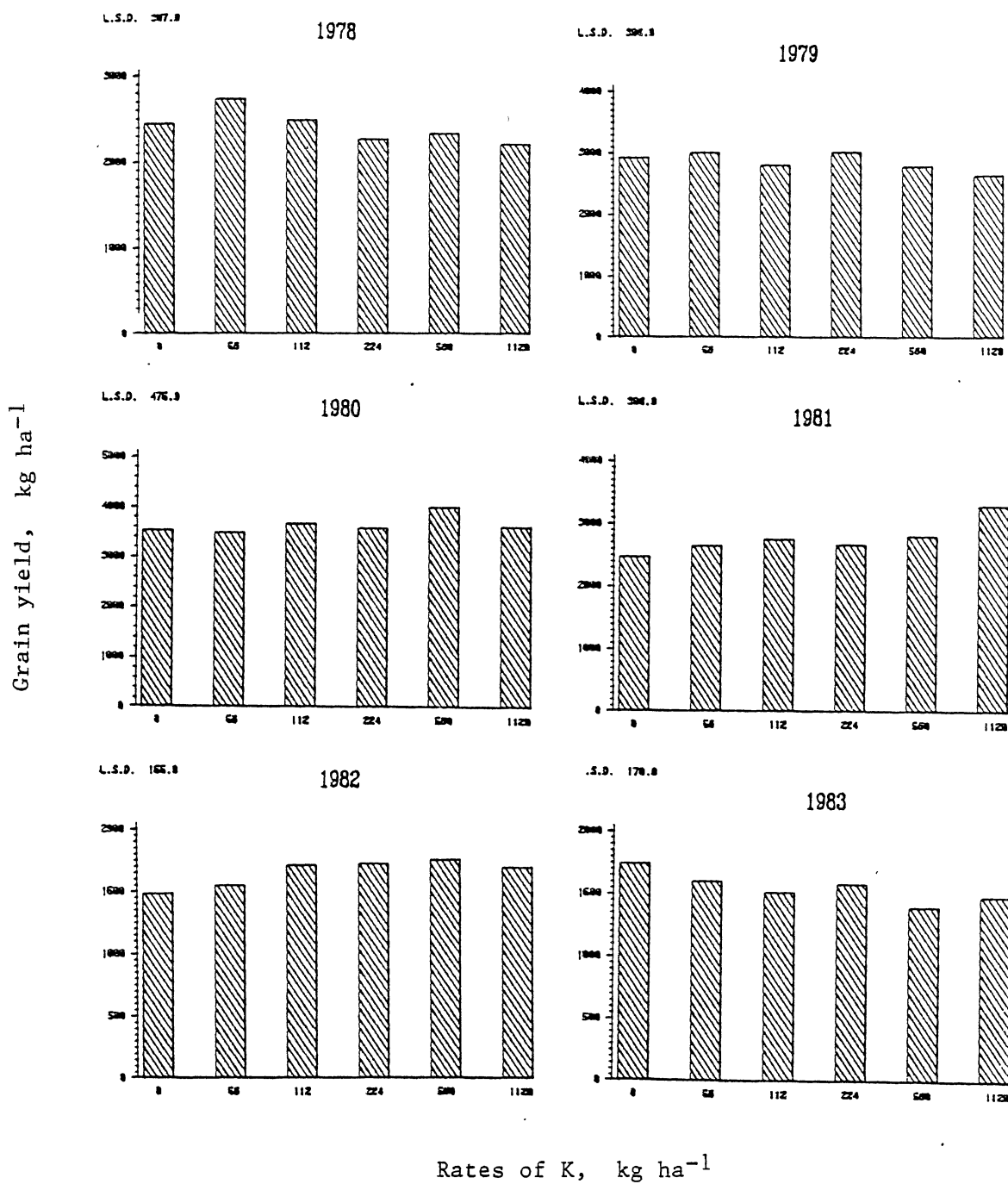


Figure 1. Grain Yield Response of Winter Wheat to K Fertilization During and After Three Years of K Fertilizer Applications

L.S.D. 125.5

GRAIN YIELD MEANS (1978-1983)

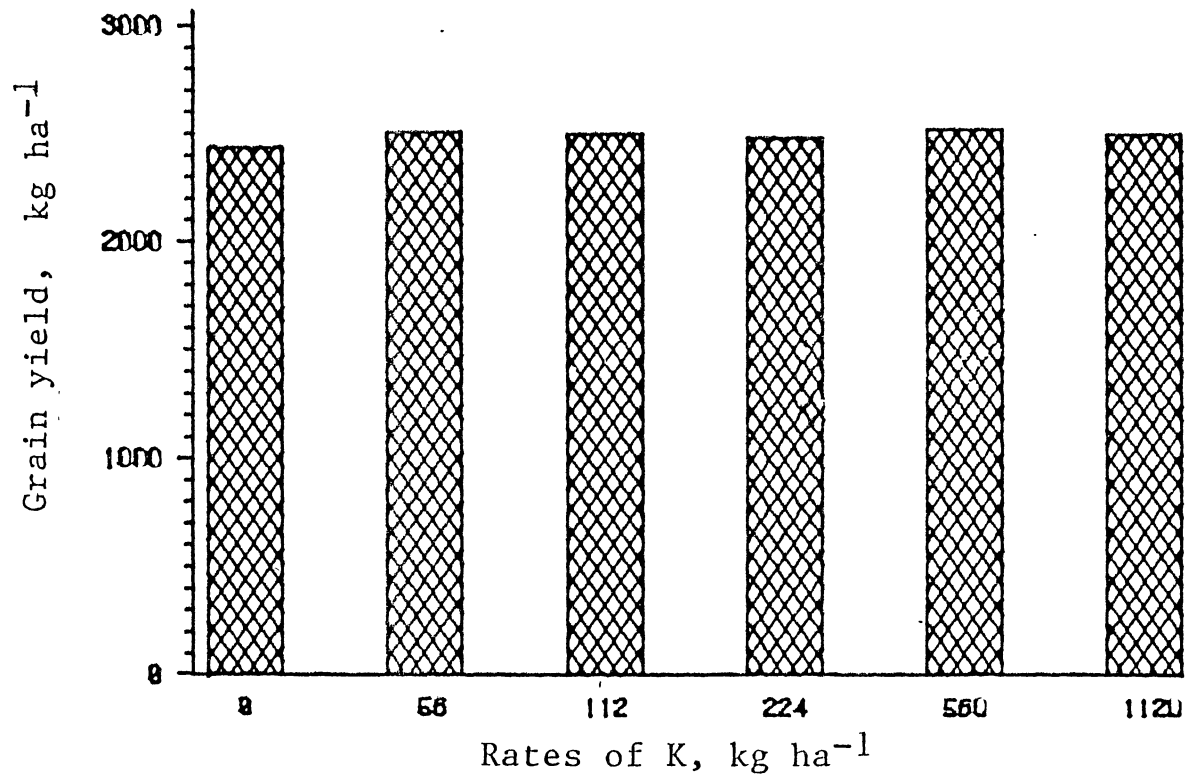


Figure 2. Long Term Effects of K Fertilization on Grain Yield Response of Winter Wheat Averaged Over Six Years

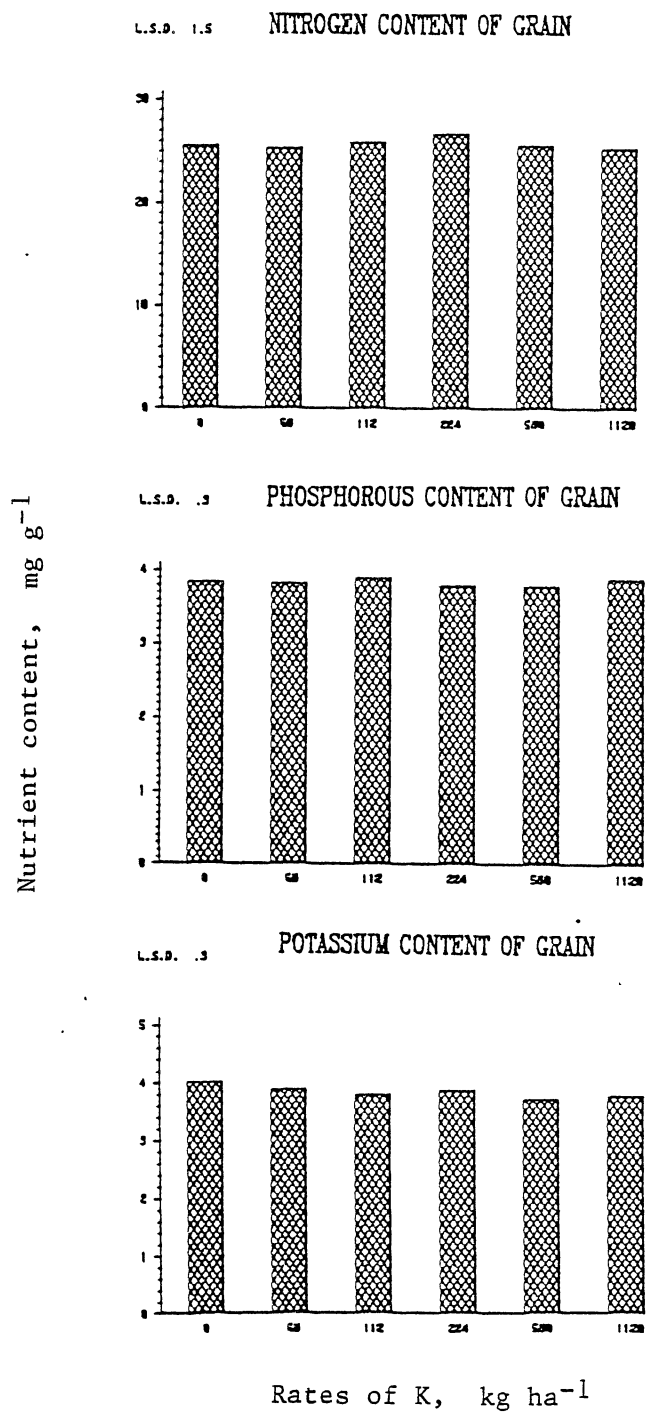


Figure 3. Long term Effects of K Fertilization on Nutrient Content of Winter Wheat Grain Averaged Over Five Years

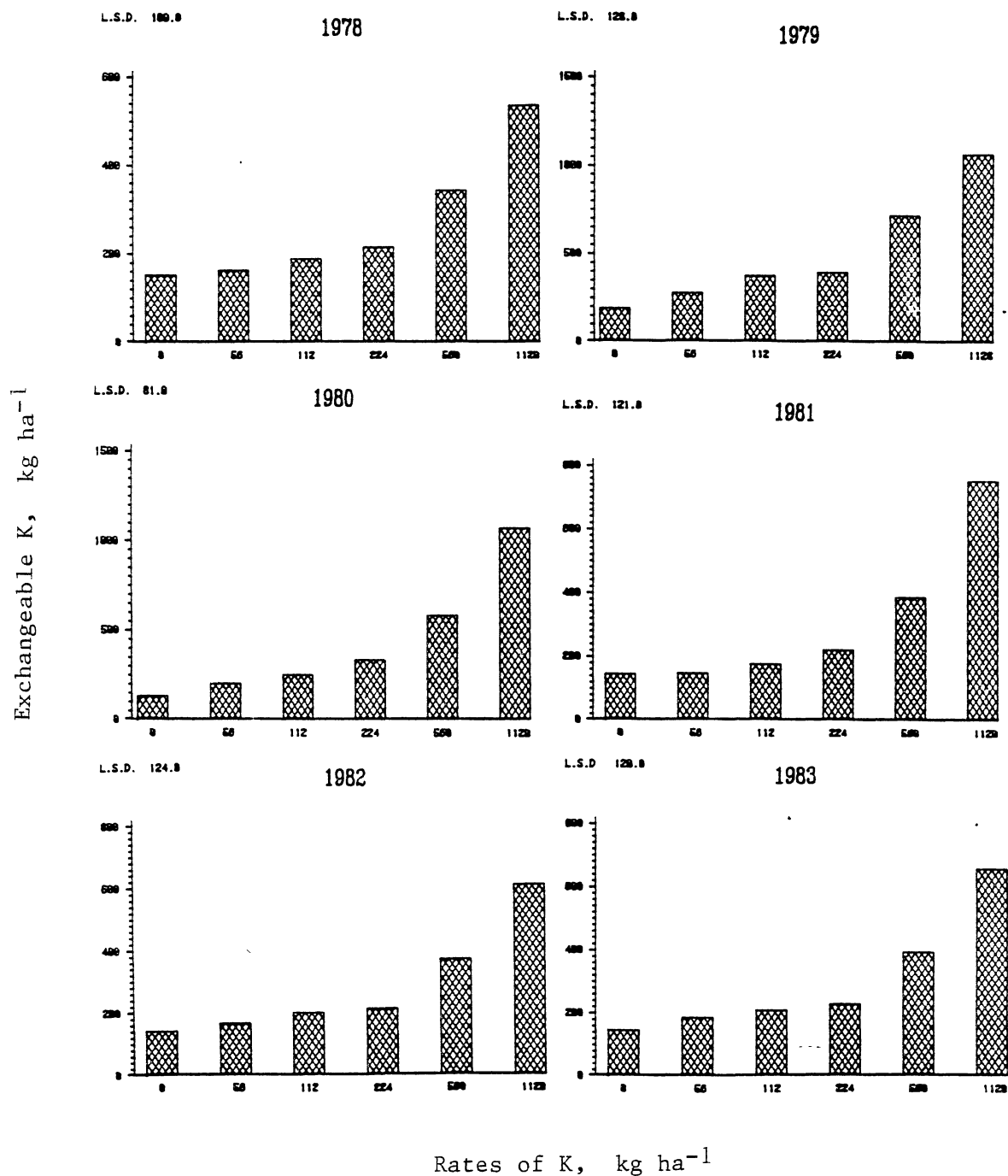


Figure 4. Immediate and Residual Effects of K Fertilization Applications on Exchangeable K in Surface Soil (0 to 15 cm) of a Taloka Silt Loam

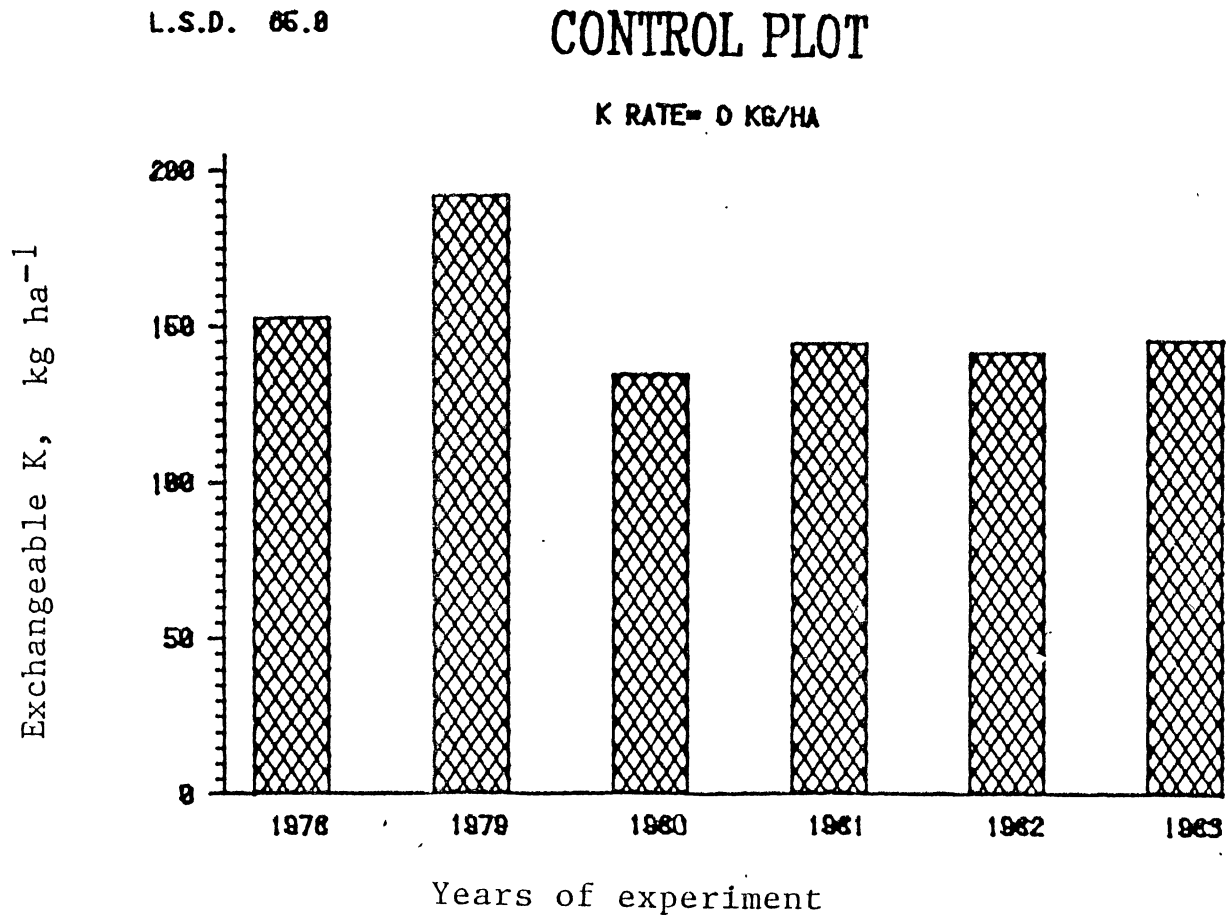


Figure 5. Concentration of Exchangeable K in Surface Soil (0 to 15 cm) of Control Plots on a Taloka Silt Loam

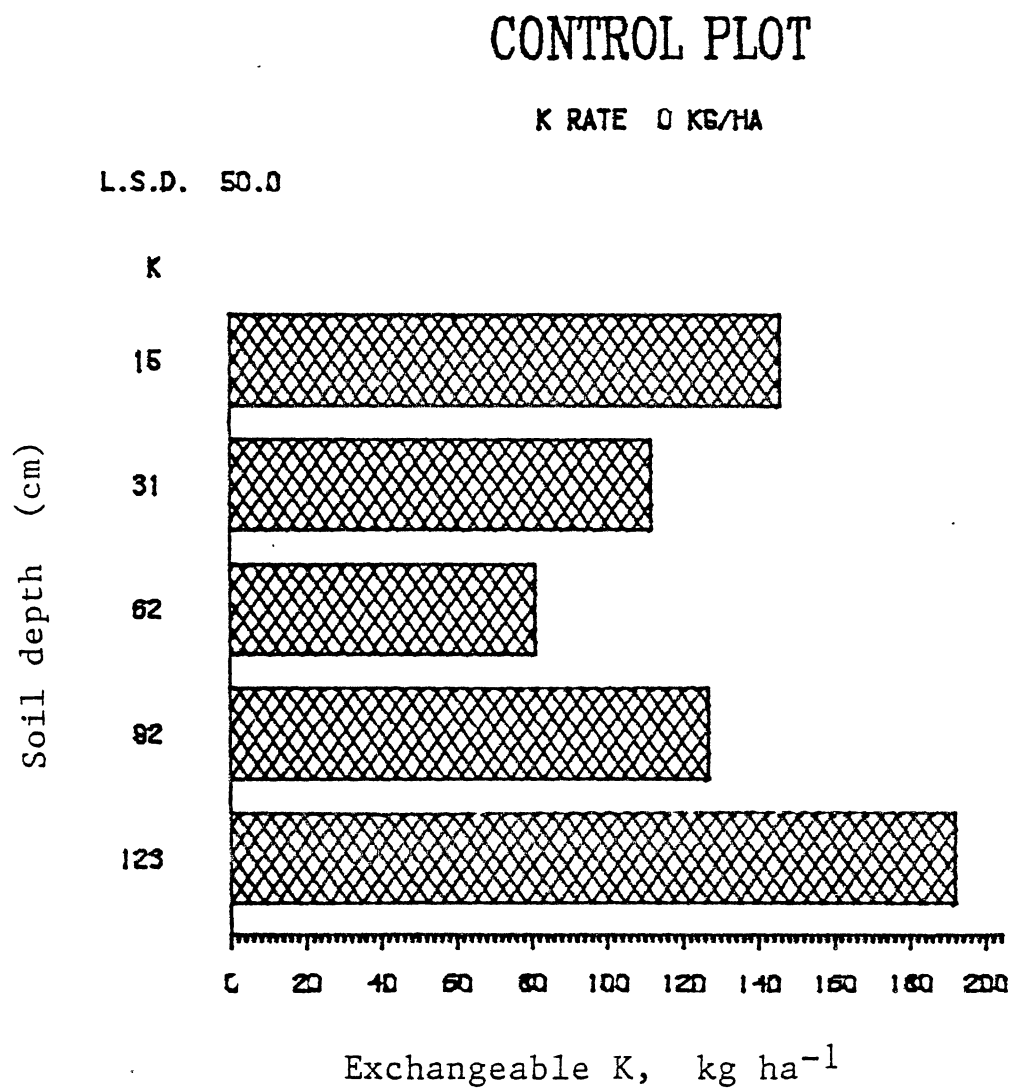


Figure 6. Exchangeable K by Depth in Control Plots of a Taloka Silt Loam, 1983

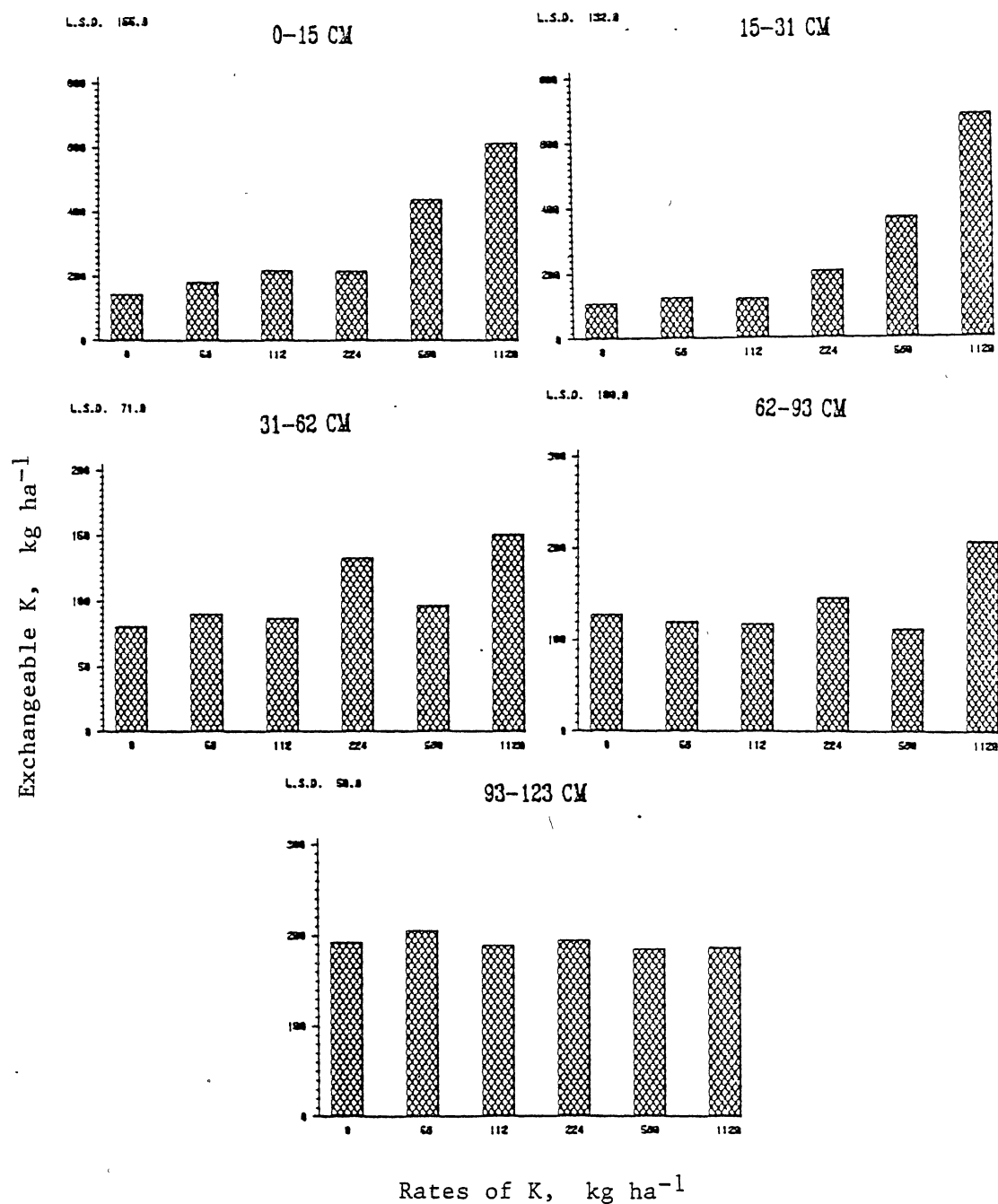


Figure 7. Effects of Surface Applied K Fertilizer on Exchangeable K Concentration Throughout the Soil Profile

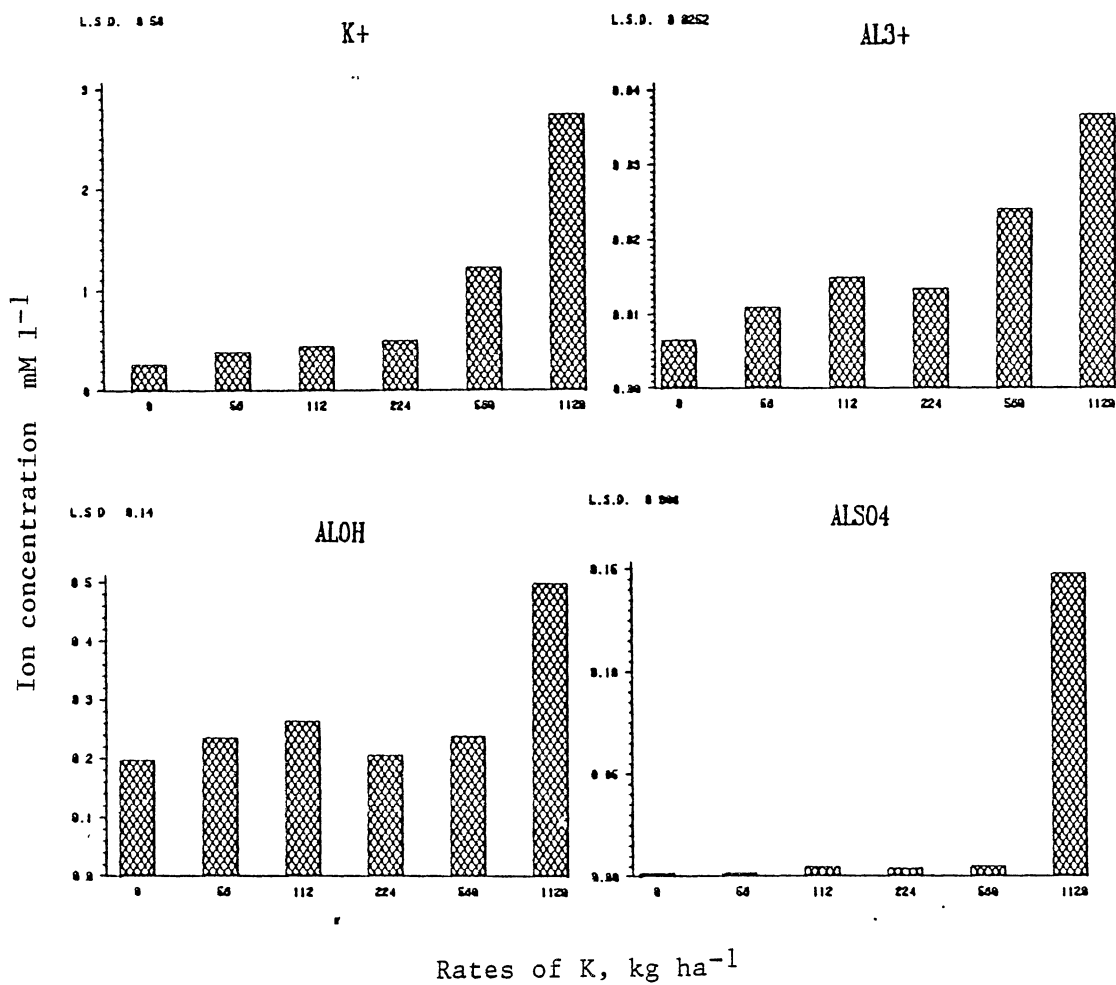


Figure 8. Effects of K Fertilization on Concentration of Selected Ionic Species in the Soil Solution of a Taloka Silt Loam

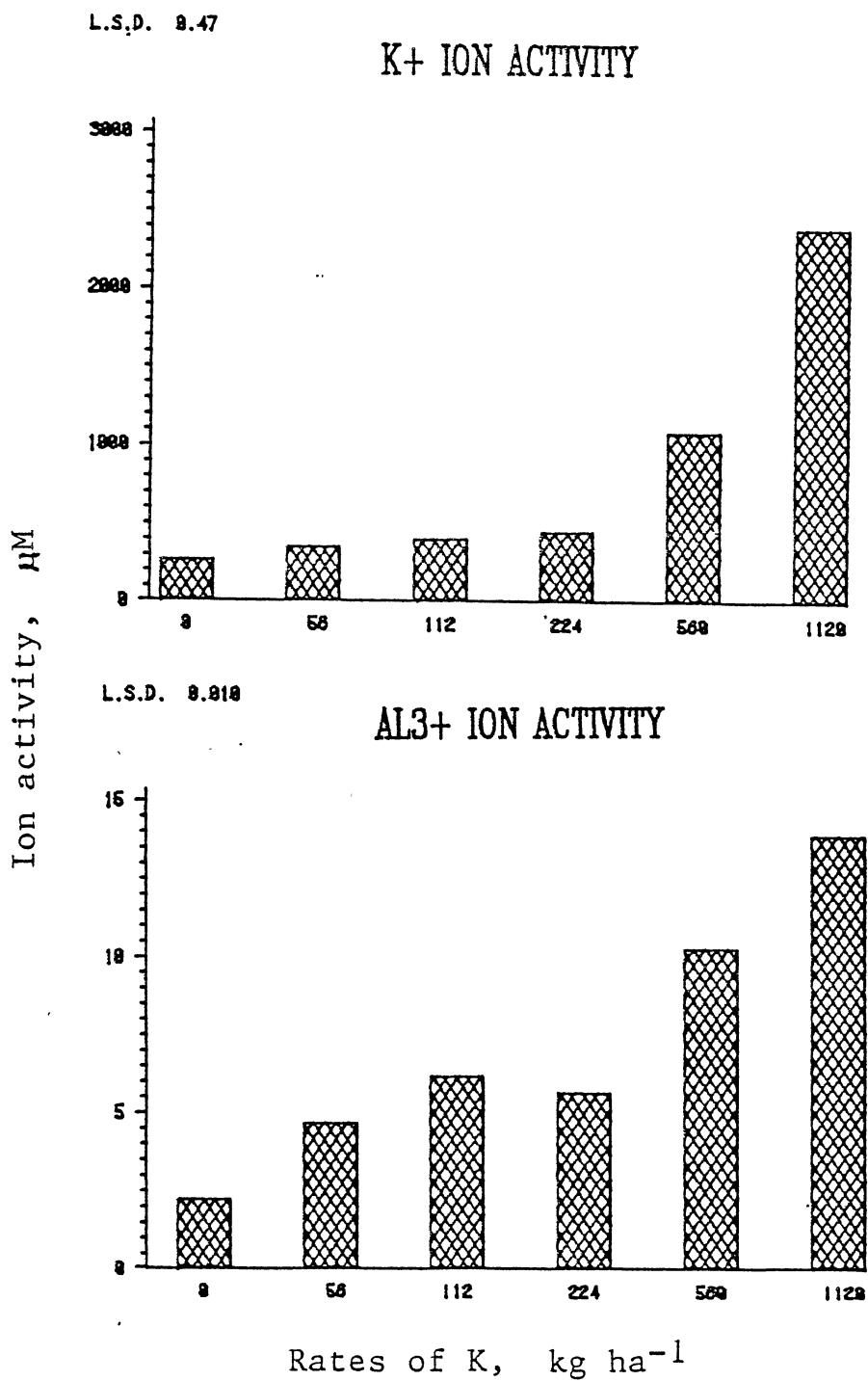


Figure 9. Effects of K Fertilization on the Ion Activity of K⁺ and Al³⁺ in the Soil Solution of a Taloka Silt Loam

VITA 2

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