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Effect of Detergent-Laden Water
on the Growth of Corn

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PREFACE

Increased use of synthetic detergents during the past two decades has compounded the disposal problems caused by sewage sludges and effluents. Possibilities of utilizing sewage sludges as fertilizer and soil conditioners or sewage effluents as irrigation water caused concern about pollution that detergent ingredients may introduce. This applies especially to the inorganic ingredients since biodegradable organic components are broken down by conventional secondary waste treatment processes. With this in mind, an investigation was initiated to study the effects of detergents on corn seedling growth. The main objectives were to determine the tolerance level of corn with regard to levels of detergent application on a wide variety of soils. An effort was made to identify the inorganic components of detergents responsible for major detrimental effects on the growth of the plants.

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ABSTRACT

A greenhouse experiment was conducted to determine the effects of two detergents on the growth of corn (Zea mays L.) when the detergent was individually applied to Davidson clay loam and Norfolk fine sandy loam. The detergents used were a heavy-duty non-enzyme detergent (Bz) and a heavy-duty enzyme detergent (Tx). These were applied in irrigation water at concentrations of 0, 20, 800, 1600, 4800, 8000, 10,000, 12,000, and 14,000 ppm.

Stimulations in growth occurred on the Davidson soil that received 1600 ppm Bz and 800, 1600, 4800, and 8000 ppm Tx, and on the Norfolk soil that received 800 ppm Tx. These stimulations were attributed to responses to phosphorus contained in the detergents.

Abnormal growth characteristics were observed on many treatments, and yield decreases were noted on the Davidson soil that received 8000, 10,000, 12,000, and 14,000 ppm Bz and 14,000 ppm Tx. Regression analyses showed that the detrimental effects on plant yields were due to soluble salt damages caused by the sodium in the detergents on all treatments except where Tx was applied to the Norfolk soil. In the latter case, specific sodium effects could not be separated from general salinity effects. Detergent Bz was more detrimental to plant growth than Tx. Plants grown on the Davidson soil were more tolerant to detergent applications than those grown on the Norfolk soil, probably because of the larger cation exchange capacity and higher magnesium content of the Davidson soil.

INTRODUCTION

The use of synthetic household detergents has increased greatly during the past 30 years, from 30 million pounds in 1940 to 5 billion pounds in 1966 (5). There has also been growing interest in the use of soils as a disposal medium for domestic sewage (6, 16). Some concern has arisen regarding pollution by detergents or detergent components when contained in sewage sludges that may be used as fertilizers or soil conditioners, or in effluent waters that may be used for irrigation. Evidence of this concern has been apparent in Europe where the addition of sodium perborate and borax to detergents has been restricted. This action was necessary because the boron salts remained in effluent water and adversely affected crops when this water was used for irrigation (7).

Because only biodegradable organic constituents are broken down by conventional secondary waste treatment processes, the inorganic detergent components remain in sewage sludges or effluents. Detrimental effects on plant growth might become evident if these materials are applied to soils as a means of disposal or if they are discharged to surface waters that are used for irrigation. Very little research has been done to investigate the effects of complete synthetic household laundry detergent formulations on plant growth. Therefore, the objectives of this investigation were as follows:

1. To ascertain the effects of various concentrations of two detergents on the growth of corn.
2. To determine the response different soils display with respect to the amount of detergent applied and the occurrence of any beneficial or detrimental effects of plant growth.
3. To identify the inorganic components present in detergents that might be responsible for beneficial or detrimental effects on plant growth.

MATERIALS AND METHODS

A greenhouse experiment was conducted to determine the effect of detergent applications on the growth of corn (*Zea mays* L.). Two soils, a Davidson clay loam and a Norfolk fine sandy loam, were selected for the investigation. Selection of the two soils was based on their agricultural importance in Virginia and their differences in physical and chemical properties. Two detergents, a heavy-duty enzyme detergent (Tx) and a heavy-duty non-enzyme detergent (Bz), were chosen for the investigation. These detergents were chosen because of their extensive usage and difference in enzyme content.

I. Greenhouse Experiment

In the greenhouse experiment surface soil material was used, 0- to 15- cm layer of a Davidson clay loam and a thick surface phase of a Norfolk fine sandy loam (Table 1). Each soil was air dried, sieved through a four-mesh stainless steel screen, and mixed. A subsample of each soil was sent to the Virginia Tech Soil Testing Laboratory for pH, organic matter, and available Ca, K, Mg, and P determinations by quick test procedures (23). These results (Table 1) were used in conjunction with Lime Use Guides (11, 12) to estimate the quantity of dolomitic limestone required to attain a soil pH of approximately 6.5 and with Soil Fertility Guides (10, 13) to evaluate the level of P and K applications required for the greenhouse study.

Amounts of lime applied per 2.268 kg soil were 4.6 and 6.8 gm dolomitic limestone for the Davidson clay loam and the Norfolk fine sandy loam, respectively. All pots received an application of 1.8 gm of a 16-8-8 commercial fertilizer. The amended soils were mixed for one minute in a twin-shell blender and placed in plastic lined pots. Applications of 1.8 gm of 16-8-8 fertilizer supplied 288 mg N, 63 mg P, and 120 mg K. Six kernels of Pioneer 3369A seed corn were planted in each pot at a depth of approximately 2.5 cm and the day after planting treatments were initiated by watering with the various detergent solutions.

Treatments consisted of applications of distilled water containing, 0, 20, 800, 1600, 4800, 8000, 10,000, 12,000, and 14,000 ppm of either Tx or Bz. The concentrations of detergents included 20 ppm because concentrations of this magnitude are normally found in raw sewage (3); 1600 ppm because it is the magnitude normally found in automatic washers; and 8000 ppm because a preliminary observation indicated a retardation of plant growth at this

concentration. The other concentrations were arbitrarily chosen to obtain additional reference points. The pots for each soil were arranged in a randomized complete block design with four replications.

The initial application was used to bring the soil moisture content to field capacity and amounted to 710 ml on the Davidson clay loam and 350 ml on the Norfolk fine sandy loam. Thereafter, the pots were maintained at field capacity by daily additions of the respective solutions. The total amount of detergent applied with each treatment during the experiment is presented in Table 2.

Visual observations on growth characteristics were maintained throughout the experiment. Plants were thinned to four seedlings per pot when they were approximately 2.5 cm tall and were harvested at soil level after a growth period of twenty days. The relatively short growth period was necessary because plants receiving higher concentrations of detergent were beginning to die and therefore, to have continued the experiment would have only resulted in a decrease in harvestable tissue. At harvest time fresh weights and plant heights were measured and the plants in each pot were described. The soil in each pot was air-dried, thoroughly mixed, and stored in plastic bags.

II. Laboratory Analyses

Plant tissue samples from each pot were dried at 70°C for 48 hours, weighed, and ground to pass a 40-mesh screen in preparation for B and P analyses. The B concentration of sub-samples of ground tissue was determined by the curcumin colorimetric procedure as modified by Mulford and Martens (20). The phosphorus concentration was determined in the following manner: A 0.5-gm sub-sample was ashed at 450°C for 2.5 hours and the ash was dissolved in 100 ml 0.3N HNO₃. Phosphorus in a 10-ml aliquot of the acidic sample was then determined by the molybdovanadophosphoric acid procedure (17).

The pH of the soil samples from each pot of the greenhouse study was determined by the method reported by Peech (22). The electrical conductivity (EC) of saturation extracts of these samples was determined by the method devised by the United States Soil Salinity Laboratory Staff (25). The Na, Ca, and Mg concentrations in saturation extracts of the soil samples were determined by atomic absorption spectrophotometry.

The exchangeable sodium percentage (ESP) was computed by the following equation:

$$\text{ESP} = \frac{100 (-0.0126 + 0.01475x)}{1 + (-0.0126 + 0.01475x)}$$

where x equals the sodium adsorption ratio. The sodium adsorption ratio (SAR) was calculated from the relationship

$$\text{SAR} = \text{Na}^+ / [(\text{Ca}^{++} + \text{Mg}^{++})/2]^{1/2}$$

where Na, Ca, and Mg are expressed in milliequivalents per liter (25).

Samples of the two detergents were sent to St. Louis Testing Laboratories, Inc., for As, B, Ca, K, Mg, Na, and P analyses. This laboratory was chosen because of their experience with detergent analyses.

III. Statistical Analyses

Data on plant growth, yield, soil, and plant tissue analyses were subjected to an analysis of variance and the Duncan's Multiple Range Test (9). Relationships between corn yield and B concentration in plant tissue, soil pH, EC of saturation extracts, and ESP of the soils were investigated by partial and multiple correlation and regression analyses using the BMD03R computer program (8).

RESULTS AND DISCUSSION

I. Visual Observation of Plant Growth

Delays in seedling emergence were observed on both soils treated with higher levels of detergent (Table 3). Seedling emergence on the control and lower rates of application began five days after planting. Seedling emergence was delayed until the eighth day after planting on the Davidson clay loam which received solutions containing 14,000 ppm Tx and on the Norfolk fine sandy loam that received solutions containing 10,000, 12,000, and 14,000 ppm Bz and 8000, 10,000, 12,000, and 14,000 ppm Tx.

The coleoptiles of seedlings emerging on the sixth and seventh day after planting has a yellow or whitish-yellow tint. Seven days after planting, leaf expansion began on treatments that received solutions containing less than 4800 ppm detergent, but where solutions containing 4800 ppm detergent or more were applied, the seedlings began to bend up to 90°, resulting in growth parallel to the soil surface. Nine days after planting some of the bent plants began to straighten, but there seemed to be some injury as evidenced by chlorotic tips and necrotic areas on the leaves.

Another abnormal growth characteristic, leaf constrictions, developed by the eleventh day. These leaf constrictions, illustrated in Figure 1, appeared in one case on a treatment as low as 1600 ppm detergent. With time, tissue within the constricted areas became chlorotic, later translucent, and finally necrotic. It was evident by the eleventh day that plants on treatments that received high concentrations of the detergents were stunted and deformed.

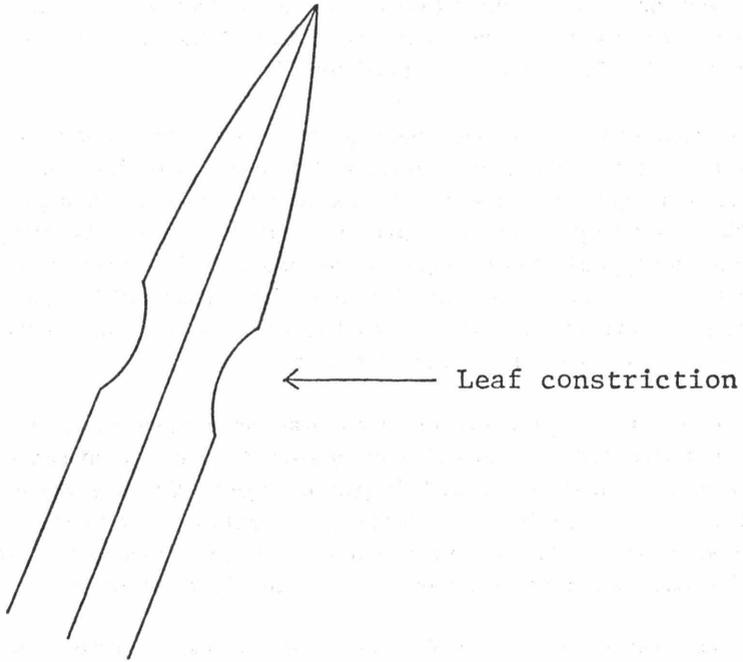
By the twelfth day many of the plants had a generally mottled appearance and were also developing interveinal chlorosis. Some of the mottled plants appeared very healthy otherwise. The eighteenth day after planting, some tip dieback was evident, and there seemed to be a recurrence of the bending. However, the bending was not as severe as that observed on the seventh day.

II. Plant Yield as Influenced by Detergents

The effect of detergent applications on the yield of corn grown on the two soils is shown in Figure 2. Application of solutions containing 1600 ppm Bz or 800, 1600, 4800, or 8000 ppm Tx increased yield on the Davidson clay loam, the maximum yield being attained at the 1600 ppm Tx rate. The only increase in yield on the Norfolk fine sandy loam occurred where solutions

FIGURE 1

Sketch of a Leaf Constriction



containing 800 ppm Tx were applied to the soil.

Application of solutions containing 8000 through 14,000 ppm Bz or 14,000 ppm Tx decreased yield of corn on the Davidson clay loam. Yield decreases occurred on the Norfolk fine sandy loam where solutions containing 1600 through 14,000 ppm Bz or 4800 through 14,000 ppm Tx were applied to the soil (Figures 2, 3, 4, 5). These data indicate that plants on the Davidson clay loam withstood a higher concentration of detergent than those on the Norfolk fine sandy loam before the occurrence of injury, and that at a given concentration, injury was less severe on the Davidson clay loam, even though higher total amounts were added per treatment on the Davidson clay loam (Table 2). Furthermore, these results show that lower concentrations of Bz than Tx caused decreases in yield on both soils.

Plant height and fresh weight trends were very similar to dry weight trends (Tables 21, 22).

III. Concentrations of Inorganic Components in the Detergent and Their Effects on Plant Growth

Concentrations of As, B, Ca, K, Mg, Na, and P in Bz and Tx are presented in Table 4. These analyses were used to determine if there were sufficient quantities of any element present in the detergents to either promote or adversely affect plant growth. From these data it was decided that P may be present in sufficient amounts to induce P responses on some treatments and that As, B, or Na may be present in sufficient quantities to cause detrimental effects on plant growth in certain cases.

a. Phosphorus

Phosphorus content in plant tissue was determined for the controls and for treatments where detergent applications increased yield. A comparison of yield data (Figure 2) and P content in tissue (Tables 5, 6) indicates that the percent P in tissue ranged from 0.28% to 0.68% for treatments where detergent applications increased yield. In all cases the percent P was below the 0.8% level at which maximum yields were obtained for 21-day-old corn by Garg and Welch (14). These results suggest that the increase in available P may have stimulated growth.

b. Arsenic

The maximum amount of As applied in any treatment was 98 μ g. This amount

FIGURE 2

Yield of Corn Grown on Davidson Clay Loan as Affected by Applications of Detergent Bz

(See Table 17)

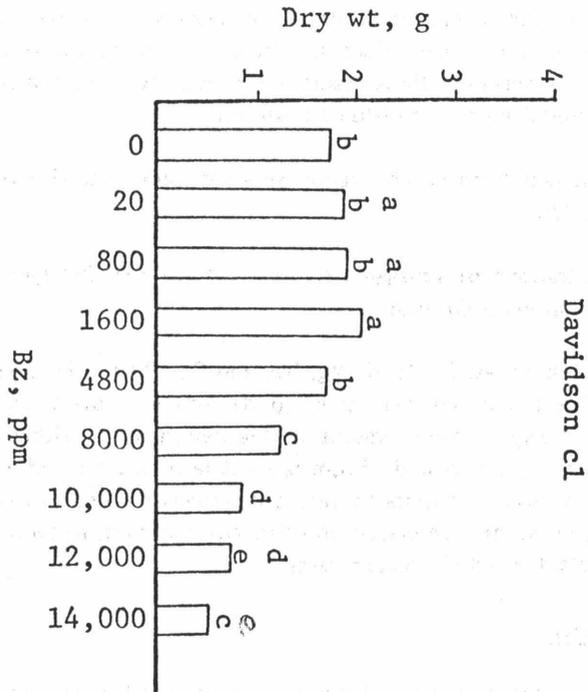


FIGURE 3

Yield of Corn Grown on Davidson Clay Loam as
Affected by Applications of Detergent Tx

(See Table 18)

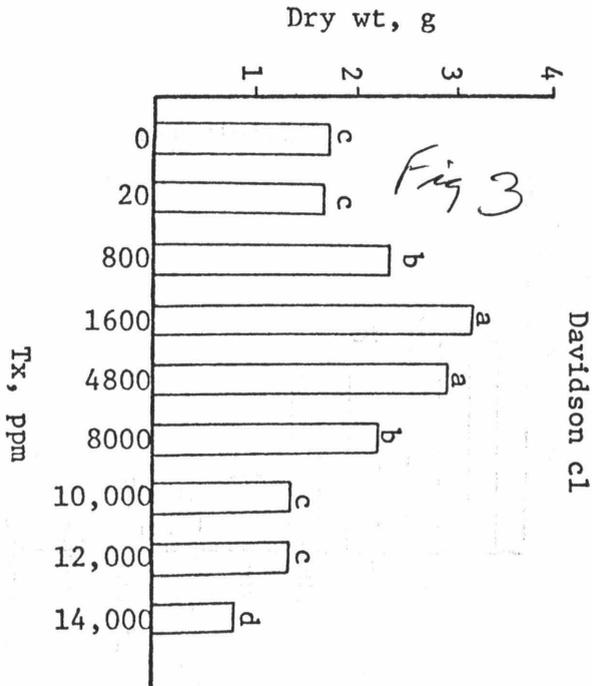


FIGURE 4

Yield of Corn Grown on Norfolk Fine Sandy Loam
as Affected by Applications of Detergent Bz

(See Table 19)

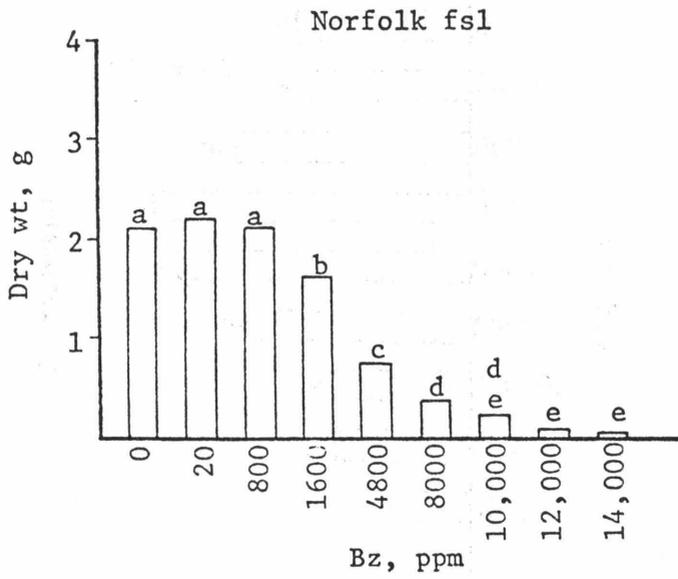
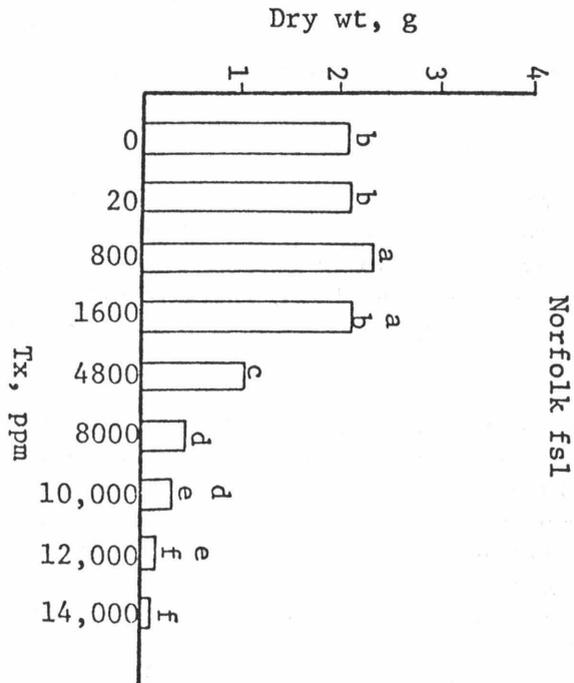


FIGURE 5

Yield of Corn Grown on Norfolk Fine Sandy Loam
as Affected by Applications of Detergent Tx

(See Table 20)



was applied to the Davidson soil in the 14,000 ppm Bz solution and would be sufficient to increase the As concentration of the soils by approximately 0.043 ppm. An increase of this magnitude seems to be negligible when compared to results obtained by Small and McCants (24) which show that As concentrations in soils were not increased by the use of arsenical insecticides in tobacco production. In addition, Williams and Whetstone [as cited by Liebig (18)] found As concentrations of 0.3 to 38.0 ppm in virgin and cropped soils. Of these soils 30% contained 5 ppm As or less, 50% ranged from 5 to 10 ppm, and 20% contained more than 10 ppm. Under the aerobic conditions of this study, the As added in detergents would remain in the less toxic pentavalent form rather than the trivalent form (15). These reports emphasize the irrelevance of a maximum increase of 0.043 ppm As in the soil.

c. Boron

The concentrations of B in the various detergent solutions were calculated on the basis of the detergent analyses (Table 4) and are presented in Table 7. Since the B concentrations of some of the detergent solutions were greater than the 1 to 2 ppm tolerance level in irrigation water used for corn production (1), B toxicity may be expected at the higher rates of applications.

The highest B concentration in tissue, 133.2 ppm, occurred where the solution containing 12,000 ppm Bz were applied to the Norfolk soil (Table 8). Martens* reported a higher B concentration in 5-week-old corn tissue of the same variety as used herein without yield decreases. Allison (2) concluded that in leaves normally associated with the development of B toxicity, concentrations of B are greater than 250 ppm. Oertli and Kohl (21) found that B concentrations in green, chlorotic, and necrotic leaf areas of young corn showing B toxicity were in the range of 360 to 790, 490 to 1160, and 1220 to 12,860 ppm, respectively. It seems reasonable to conclude from the B concentrations in plant tissue (Table 8) and the research cited above that B toxicity was not responsible for decreases in corn yield due to detergent applications.

d. Sodium

The Na concentration in Bz was 21.0% and in Tx was 21.5% (Table 4) which gives a concentration range of 0 to 2800 ppm Na in the solutions used. Applications of detergent solutions with relatively high Na concentrations

*Personal communication: David C. Martens, Agronomy Department, Virginia Polytechnic Institute and State University.

will increase the Na content of the soil with the subsequent increase in EC and ESP.

A comparison of the EC data (Table 9) and the yield data (Figure 2) shows that decreases in yield were initiated at EC values of 7.7 mmhos/cm and 8.5 mmhos/cm on the Davidson Bz and Tx treatments, respectively. The corresponding EC values for the Norfolk Bz and Tx treatments are 8.3 mmhos/cm and 10.1 mmhos/cm, respectively. These results correspond to earlier findings on effect of EC on yields (2, 25) and therefore, indicate that an increase in EC, mainly caused by Na in the detergents, may have contributed significantly to the reduction in tissue yields.

Detergent applications increased the ESP on the Davidson clay loam to a maximum of 35.0% and on the Norfolk fine sandy loam to a maximum of 60.7% (Table 10).

Rhoades* reported that Na toxicity occurs in young sweet corn at an ESP of approximately 25%. He also indicated that this ESP level refers only to the direct toxic effect of sodium on corn growth in the absence of adverse physical properties of soil and if an ESP of this level or lower causes structural breakdown of the soil, then this problem will supersede that of Na toxicity per se. However, Allison (1) shows that on a Pachappa loam with an ESP of 15%, the yield of Golden Bantam corn was reduced by 50%. Lunt (19), who reviewed relationships between ESP and plant growth, states that deterioration of soil physical properties becomes increasingly pronounced as the ESP exceeds 10 to 20% and mentions that Na injury occurs at lower ESP's in the greenhouse than in the field. By comparing the ESP (Table 10) and the yield data (Figure 2), it can be seen that decreases in yield were first observed on the Davidson Bz and Tx treatments at ESP values of 18.1 and 35 percent, respectively. On the Norfolk soil decrease in yield was first obtained at ESP value of 9.4% where 1600 ppm Bz was applied. On the Tx treatments, an ESP value of 23.5% caused the first yield decrease at the 4800 ppm rate.

The results (Tables 9 and 10) when compared to yield data (Figure 2) indicate that EC and ESP values may both be responsible for the decrease in plant tissue yield. Since the EC and ESP are both highly dependent on the Na component in the detergents, separation of their individual effects becomes a necessity as shown in the section dealing with multiple regressions.

*Personal communication: James D. Rhoades, Soil Scientist, U.S. Salinity Laboratory, Riverside, California

IV. Effect of Detergents on Soil pH

The pH levels of the detergent solutions under study were determined, and it was found that the pH levels of all solutions, except the 20 ppm Bz and Tx solutions, ranged from 9.0 to 9.7 (Table 11). The pH of the soil in each treatment was measured to determine if applications of detergent solutions increased the soil pH to detrimental levels. Soil pH varied from a low of 5.8 on the Norfolk soil that received solutions containing 800 ppm Bz to a high of 7.2 on the Norfolk soil that received solutions containing 14,000 ppm Tx, a difference of 1.4 units (Table 12). Epperson and Hawkins (12) reported that the most favorable pH range for corn is 6.1 through 7.3 and that corn may grow fairly well to normal in the pH range of 5.6 through 6.0. Hence, it was concluded that the application of detergent solutions did not increase the soil pH to levels that were detrimental to corn.

V. Correlation Analyses for Relationships Between Plant Yield and Selected Variables

Evidence reported in previous sections indicates that changes in B availability and soil pH due to detergent applications were not responsible for decreases in yield, but that the increases in soluble salts (resulting mainly from Na contained in the detergents) caused the decreases in yield. Multiple and partial correlation analyses were conducted to support these conclusions. The dependent variable in these analyses was yield, and the independent variables were B concentrations in plant tissue, soil pH, EC of saturation extracts, and ESP. For each analysis, those treatments were deleted which received lower detergent concentrations than the treatment on which maximum yields were measured. This procedure was followed to avoid confounding effects over the range where yields increased due to detergent applications.

The coefficients of multiple correlation between yield and the four independent variables ranged from 0.908 to 0.969 where solutions of the two detergents were applied to the Davidson and Norfolk soils (Tables 13, 14, 15, and 16). The determination coefficients show that the four variables accounted for 82.4 to 93.8 percent of the variation in yield. When the independent variables, B concentration in plant tissue and soil pH, were deleted from the analyses, and yield was correlated with EC of saturation extracts and ESP, 81.9 to 93.6 percent of the variation in yield was explained. This slight loss of dependent variation and the non-significance of the partial correlations coefficients for B and pH in plant tissue substantiate previous conclusions that the B addition and pH change due to detergent applications had no adverse effects on plant growth.

The coefficients of multiple correlation ranged from 0.905 to 0.968 where yield was correlated with the independent variables, EC of saturation extracts, and ESP, omitting B and pH. The non-significance of the coefficients of partial correlation for EC of saturation extracts shows that only ESP contributed to the correlation where Bz and Tx were applied to the Davidson clay loam and where Bz was applied to the Norfolk fine sandy loam (Tables 13, 14, and 15). The coefficients of partial correlation for EC were significant only for the Tx treatments on the Norfolk soil (Table 16) where the salinity effects could not be separated from the ESP effects.

The partial correlation coefficients suggest that the exchangeable Na added to the soils by the detergents was mainly responsible for the reduction in the vegetative growth of the corn plants. When the EC and ESP values (Tables 9 and 10) are related to the plant tissue yields (Figure 3), it would seem that the EC values should give the best indicator for detrimental effects since all treatments with EC values above 7.5 mmhos showed reduction in plant growth, whereas the corresponding ESP values varied between 9.4 and 35.0 percent. However, as shown, the partial correlation coefficients indicate that the ESP is the main contributor towards reduction in plant growth. The reason is that the EC is in itself a dependent variable of exchangeable Na added and hence, dependent on the ESP. Bower, *et al.* (4) reported a similar situation between effects of pH and exchangeable Na on yields of sugar beets.

Unfortunately, no definite explanation could be formulated as to why detrimental effects on plant growth were obtained at widely different ESP values over the various treatments (Table 10). The difference observed between soils may be explained by the difference in cation exchange capacity (CEC) and Mg content in these soils (Table 1). On the Norfolk soil, which has a lower CEC and less Mg as compared to the Davidson soil, Na additions will induce Mg deficiency at a lower Na level. The difference in ESP values between the two detergent treatments cannot be explained since the actual structural components of the detergents are not known. A possible factor may be a differential ability for sequestering Ca and Mg thereby differentially inducing Ca and Mg deficiency; however, there is no proof that this is the case.

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted to determine the effect of detergents contained in irrigation water on the growth of corn (*Zea mays* L.) on a Davidson clay loam and a Norfolk fine sandy loam. The soils were maintained at approximately field capacity with solutions containing various concentrations of either a heavy-duty non-enzyme laundry detergent (Bz) or a heavy-duty enzyme detergent (Tx). The detergent concentrations used were 0, 20, 800, 1600, 4800, 8000, 10,000, 12,000, and 14,000 ppm.

Yield increases were observed on the Davidson clay loam on treatments that received 800, 1600, 4800, and 8000 ppm Tx and 1600 ppm Bz. The only yield increase which was observed on the Norfolk fine sandy loam occurred on the 800 ppm Tx treatment. These yield increases were attributed to an increase in P availability from the P contained in the detergents.

Abnormal growth characteristics such as plant bending, the development of leaf constrictions, interveinal chlorosis, mottling, and tip dieback were observed in corn on many treatments. Yield decreases occurred on the Davidson clay loam on treatments that received 8000, 10,000, 12,000, and 14,000 ppm Bz and 14,000 ppm Tx. Yield decreases on the Norfolk fine sandy loam were obtained with treatments of 1600, 4800, 8000, 10,000, 12,000, and 14,000 ppm Bz and 4800, 8000, 10,000, 12,000, and 14,000 ppm Tx. Corn yields were compared with soil pH, EC of soil saturation extracts, ESP of the soils, and B concentrations in plant tissue to determine the factor responsible for yield decreases. Based on these comparisons, it was concluded that the Na content of the detergents was mainly responsible for the decrease in yield on all treatments except where Tx was applied to the Norfolk fine sandy loam. In the latter case, the general salinity effects as measured by EC could not be separated from specific Na effects as measured by ESP.

Plants withstood higher concentrations of detergents on the Davidson clay loam than on the Norfolk fine sandy loam. The severity of plant injury was less on the Davidson clay loam, probably because of its larger cation exchange capacity and higher Mg content. Detergent Bz was more detrimental with respect to plant yield than Tx. This effect could not be explained on the basis of soil pH, EC of saturation extracts, ESP of the soils, B concentration in plant tissue or the inorganic composition of the detergents. Possible factors that may have to be considered are differential ability between detergents for sequestering Ca and Mg, and the availability of phosphates which will be related to the structural compositions of the detergents.

LITERATURE CITED

1. Allison, L. E. 1956. Soil and Plant Responses to VAMA and HPAN Soil Conditioners in the Presence of High-exchangeable Sodium. *Soil Sci. Soc. Amer. Proc.* 20:147-151.
2. Allison, L. E. 1964. Salinity in Relation to Irrigation. *Advance. Agron.* 16:139-180.
3. Anonymous. 1969. Detergent Enzymes: Biodegradation and Environmental Acceptability. *BioScience* 19:1093-1094.
4. Bower, C. A., C. D. Moddie, P. Orth, and F. B. Gschwend. 1954. Correlation of Sugar Beet Yields with Chemical Properties of a Saline-alkali Soil. *Soil Sci.* 77:443-451.
5. Brenner, T. E. 1969. Biodegradable Detergents and Water Pollution. In *Advances in Environmental Sciences*, p. 147-196. John Wiley and Sons, New York, N. Y. Vol. 1.
6. Conn, Richard. 1970. Liquid Sludge as a Farm Fertilizer. *Crops and Soils* 22:12-13.
7. Davidson, A., and B. M. Milwidsky. 1967. *Synthetic Detergents*. 4th ed., p. 1-65. Leonard Hill Books., Strand, London, England.
8. Dixon, W. J. (ed.) 1971. *BMD, Biomedical Computer Programs*, Univ. of Calif. Publications in Automatic Computation. 2nd ed., p. 258-275c. Univ. of Calif. Press at Berkely and Los Angeles, California.
9. Duncan, D. B. 1955. Multiple Range and Multiple F Tests. *Biometrics* 11:1-42.
10. Epperson, G. R., and G. W. Hawkins. 1966. *Soil Fertility Guides for the Coastal Plains Region of Virginia*. Virginia Polytechnic Institute Ext. Div. Bull. 297.
11. Epperson, G. R., and G. W. Hawkins. 1968. *Lime Use Guides for the Coastal Plains Region of Virginia*. Virginia Polytechnic Institute Ext. Div. Pub. 106.

12. Epperson, G. R., and G. W. Hawkins. 1968. Lime Use Guides for the Piedmont Plains Region of Virginia. Virginia Polytechnic Institute Ext. Div. Pub. 108.
13. Epperson, G. R., G. W. Hawkins, and G. D. McCart. 1971. Soil Fertility Guides for the Piedmont Region of Virginia. Virginia Polytechnic Institute and State Univ. Ext. Div. Pub. 429.
14. Garg, K. P., and L. F. Welch. 1967. Growth and Phosphorus Uptake by Corn as Influenced by Phosphorus Placement. *Agron. J.* 59:152-154.
15. Harris, A. J., K. J. Roberts, and A. E. Christie. 1971. Effects of Detergents on Water Supplies. *J. AWWA* 63:795-799.
16. Hinsley, T. B., and S. Sosewitz. 1969. Digested Sludge Disposal on Crop Land. *J. WPCA* 41:822-830.
17. Kitson, R. E., and M. G. Mellon. 1964. Colorimetric Determination of Phosphorus as Molybdivanadophosphoric Acid. *Ind. Eng. Chem. (Anal. Ed.)* 16:379-383.
18. Liebig, G. F., Jr. 1966. Arsenic. In *Diagnostic Criteria for Plants and Soils*. Homer D. Chapman (ed.) p. 13-23. Univ. of Calif., Division of Agricultural Sciences.
19. Lunt, O. R. 1966. Sodium. In *Diagnostic Criteria for Plants and Soils*. Homer D. Chapman (ed.) p. 409-432. Univ. of Calif., Division of Agricultural Sciences.
20. Mulford, F. R., and D. C. Martens. 1970. A Simple Procedure for Drying Solutions for Boron Determinations by the Curcumin Method. *Soil Sci. Soc. Amer. Proc.* 34:155-156.
21. Oertli, J. J., and H. C. Kohl. 1961. Some Considerations About the Tolerance of Various Plant Species to Excessive Supplies of Boron. *Soil Sci.* 99:243-247.
22. Peech, M. 1965. Hydrogen-ion Activity. In *Methods of Soil Analysis: Chemical and Microbiological Properties*. C. A. Black (ed.) Amer. Soc. Agron., Madison, Wisconsin.

23. Rich, C. I. 1955. Rapid Soil Testing Procedures at Virginia Polytechnic Institute. Virginia Agr. Exp. Sta. Bull. 475:1-8.
24. Small, H. G., Jr., and C. B. McCants. 1962. Residual Arsenic in Soils and Concentration in Tobacco. Tobacco Sci. 6:34-36.
25. United States Salinity Laboratory Staff. 1954. USDA Agr. Handbook No. 60. L. A. Richards (ed.) p. 1-160.

APPENDIX

TABLE 1

Classification, Location, and Quick Test Data for the Two Soils Under Study

<u>Soil type</u>	7th Approximation classification	<u>Location</u>	Soil pH	Organic matter, %	Content of available			
					Ca, ppm	Mg, ppm	P, ppm	K, ppm
Davidson cl	Rhodic Paleudult	Piedmont Research Station, Orange, Virginia	5.3	2.9	825.3	120.0	3.1	110.0
Norfolk fsl thick surface phase	Typic Paleudult	Correctional Farm, Southampton, Co., Virginia	5.5	1.0	887.8	19.3	87.3	44.0

TABLE 2

Detergent Applied to the Soils Studied

<u>Detergent concentration, ppm</u>	<u>Davidson cl</u>		<u>Norfolk fsl</u>	
	<u>Bz</u>	<u>Tx</u>	<u>Bz</u>	<u>Tx</u>
	mg/2.268 kg soil			
0	0	0	0	0
20	40.4	39.1	30.9	30.6
800	1637.2	1611.0	1194.0	1210.4
1600	3163.6	3266.0	2234.8	2308.4
4800	8898.0	9390.0	5535.6	5558.4
8000	13,644.0	14,324.0	8268.0	8430.0
10,000	16,372.5	16,290.0	9920.0	9907.5
12,000	19,527.0	18,831.0	11,313.0	11,100.0
14,000	21,749.0	20,905.5	13,842.5	12,894.0

TABLE 3

Corn Seedling Emergence Compared to
Detergent Concentration

<u>Detergent concentration, ppm</u>	<u>Davidson cl</u>		<u>Norfolk fsl</u>	
	<u>Bz</u>	<u>Tx</u>	<u>Bz</u>	<u>Tx</u>
<u>Days after planting</u>				
0	5	5	5	5
20	5	5	5	5
800	4	5	5	5
1600	5	5	5	5
4800	5	6	6	6
8000	5	6	7	8
10,000	6	7	8	8
12,000	6	7	8	8
14,000	6	8	8	8

TABLE 4

Concentration of Some Elements in the
Two Detergents

<u>Element</u>	<u>Detergent</u>	
	<u>Bz</u>	<u>Tx</u>
	%	
Na	21.00	21.50
P	10.88	9.66
Ca	< 0.01	< 0.01
Mg	< 0.005	< 0.005
K	0.12	0.031
B	0.20	< 0.005
	ppm	
As	4.5	< 1.2

TABLE 5

Phosphorus Concentration in Corn Grown on Davidson Loam
as Affected by Levels of Detergent in Irrigation Water*

<u>Detergent</u>	<u>Detergent concentration, ppm</u>	<u>P in tissue, %</u>
None	0	0.23d**
Tx	800	0.32c
Tx	1600	0.47b
Tx	4800	0.58a
Tx	8000	0.66a
None	0	0.23a
Bz	1600	0.28a

*Means of four replications.

**Means for each detergent followed by the same letter are not significantly different at the 5% level.

TABLE 6

Phosphorus Concentration in Corn Grown on Norfolk Fine Sandy Loam as Affected by Levels of Detergent in Irrigation Water*

<u>Detergent</u>	<u>Detergent concentration, ppm</u>	<u>P in tissue, %</u>
None	0	0.27b**
Tx	20	0.29b
Tx	800	0.68a

*Means of four replications.

**Means followed by the same letter are not significantly different at the 5% level.

TABLE 7

Boron Concentration of the Various
Detergent Solutions

<u>Detergent concentration, ppm</u>	<u>Detergent solutions</u>	
	<u>Bz</u>	<u>Tx</u>
	ppm B	
0	0	0
20	0.040	0.001
800	1.60	0.040
1600	3.20	0.080
4800	9.60	0.240
8000	16.00	0.400
10,000	20.00	0.500
12,000	24.00	0.600
14,000	28.00	0.700

TABLE 8

Boron Concentration in Corn Grown on Two Soils as Affected by Level of Detergent in Irrigation Water*

Detergent concentration, ppm	Davidson cl.		Norfolk fsl	
	Bz	Tx	Bz	Tx
	ppm B			
0	4.6d**	4.6d**	5.7c**	5.7a**
20	5.1d	4.5d	9.1c	4.6a
800	6.1d	4.9cd	47.5bc	5.4a
1600	6.6d	5.5cd	72.0ab	7.6a
4800	30.9cd	7.9bcd	106.0ab	10.9a
8000	34.2c	8.6ab	83.1ab	9.2a
10,000	40.2bc	10.2a	111.5ab	16.9a
12,000	84.8a	7.7abc	133.2a	----†
14,000	64.1ab	5.7bcd	101.4ab	----†

* Means of four replications.

** Means followed by the same letter are not significantly different at the 5% level.

† Inadequate sample for B analysis.

TABLE 9

Electrical Conductivity of the Saturation Extracts of Two Soils as Affected
by Levels of Detergent in Irrigation Water*

<u>Detergent concentration, ppm</u>	<u>Davidson cl</u>		<u>Norfolk fsl</u>	
	<u>Bz</u>	<u>Tx</u>	<u>Bz</u>	<u>Tx</u>
	mmhos/cm			
0	3.3d**	3.3e**	6.4de**	6.4c**
20	3.4d	3.4e	5.7e	5.9c
800	3.7d	3.0e	6.8de	6.6c
1600	3.7d	3.3e	8.3d	7.0c
4800	5.7c	5.0d	11.3c	10.1b
8000	7.7b	6.6c	13.5b	12.9a
10,000	7.7b	6.4c	14.4b	12.9a
12,000	9.8a	7.5b	14.3b	12.9a
14,000	9.2a	8.5a	17.2a	13.9a

*Means of four replications.

**Means followed by the same letter are not significantly different at the 5% level.

TABLE 10

Exchangeable Sodium Percentage in Saturation Extracts of Two Soils as Affected by Levels of Detergents in Irrigation Water*

Detergent concentration, ppm	Davidson cl		Norfolk fsl	
	Bz	Tx	Bz	Tx
	%			
0	- 1.1g**	- 1.1h**	- 1.1f**	- 1.1g**
20	- 1.1g	- 1.0h	- 1.0f	- 1.0g
800	1.4f	1.3g	2.9f	3.9g
1600	4.0e	4.7f	9.4e	9.7f
4800	14.7d	18.1e	20.3d	23.5e
8000	18.1c	22.7d	28.5c	42.6d
10,000	24.5b	27.9c	39.7b	48.5c
12,000	25.6b	30.8b	51.8a	54.8b
14,000	31.7a	35.0a	54.3a	60.7a

*Means of four replications.

**Means followed by the same letter are not significantly different at the 5% level.

TABLE 11

The pH of the Detergent Solutions Under Study

<u>Detergent concentration, ppm</u>	<u>Detergent solutions</u>	
	<u>Bz</u>	<u>Tx</u>
	<u>pH</u>	
20	6.0	5.8
800	9.0	9.1
1600	9.2	9.3
4800	9.4	9.5
8000	9.4	9.5
10,000	9.4	9.6
12,000	9.5	9.6
14,000	9.6	9.7

TABLE 12

Soil pH of Davidson Clay Loam and Norfolk Fine Sandy Loam as Affected
by Levels of Detergent in Irrigation Water*

Detergent concentration, ppm	Davidson cl		Norfolk fsl	
	Bz	Tx	Bz	Tx
	pH			
0	6.0de **	6.0g **	6.0de **	6.0e **
20	5.9e	5.9fg	6.1d	6.0e
800	6.1d	6.0ef	5.8e	6.0e
1600	6.0de	6.1de	5.9e	5.9e
4800	6.3c	6.4d	6.2c	6.2d
8000	6.3c	6.4c	6.3c	6.6c
10,000	6.5b	6.6b	6.5b	6.8b
12,000	6.4b	6.6b	6.7a	7.0b
14,000	6.5a	6.7a	6.8a	7.2a

*Means of four replications.

**Means followed by the same letter are not significantly different at the 5% level.

TABLE 13

Multiple and Partial Correlation Analyses Between Yield of Corn on the Davidson Clay Loam Treated with Bz and Selected Independent Variables

<u>Dependent variable</u>	<u>Independent variable</u>	<u>Coefficients of</u>		
		<u>Multiple correlation</u>	<u>Partial correlation</u>	<u>Determination</u>
Yield	Soil pH	0.923**	-0.073ns	0.852
	B in plant tissue		-0.190ns	
	EC of sat. extract		-0.206ns	
	ESP		-0.345ns	
Yield	EC of sat. extract	0.920**	-0.229ns	0.846
	ESP		-0.631**	

ns Nonsignificant at the 10% level.

**Significant at the 1% level.

TABLE 14

Multiple and Partial Correlation Analyses Between Yield of Corn on the Davidson Clay Loam Treated with Detergent Tx and Selected Variables

Dependent variable	Independent variable	Coefficients of		
		Multiple correlation	Partial correlation	Determination
Yield	Soil pH	0.908**	0.109ns	0.824
	B in plant tissue		0.145ns	
	EC of sat. extract		0.010ns	
	ESP		-0.422†	
Yield	EC of sat. extract	0.095**	-0.075ns	0.819
	ESP		-0.547**	

ns Nonsignificant at the 10% level.

†Significant at the 10% level.

**Significant at the 1% level.

TABLE 15

Multiple and Partial Correlation Analyses Between Yield of Corn on the Norfolk Fine Sandy Loam Treated With Detergent Bz and Selected Variables

<u>Dependent variable</u>	<u>Independent variable</u>	<u>Multiple correlation</u>	<u>Coefficients of Partial correlation</u>	<u>Determination</u>
Yield	Soil pH	0.938**	0.046ns	0.881
	B in plant tissue		-0.304ns	
	EC of sat. extract		-0.362†	
	ESP		-0.418*	
Yield	EC of sat. extract	0.931**	-0.294ns	0.867
	ESP		-0.763**	

ns Nonsignificant at the 10% level.

†Significant at the 10% level.

*Significant at the 5% level.

**Significant at the 1% level.

TABLE 16

Multiple and Partial Correlation Analyses Between Yield of Corn on the Norfolk Fine Sandy Loam Treated with Detergent and Selected Variables

Dependent variable	Independent variable	Coefficients of		
		Multiple correlation	Partial correlation	Determination
Yield	Soil pH	0.969**	0.054 _{ns}	0.938
	B in plant tissue		-0.173 _{ns}	
	EC of sat. extract		-0.487*	
	ESP		-0.539**	
Yield	EC of sat. extract	0.968**	-0.541**	0.936
	ESP		-0.652**	

ns Nonsignificant at the 10% level.

*Significant at the 5% level.

**Significant at the 1% level.

TABLE 17

Yield of Corn Grown on Davidson Clay Loam as Affected
by Applications of Detergent Bz

Detergent concentration, ppm	Replication				Avg.
	<u>I</u>	<u>II</u>	<u>III</u>	<u>IV</u>	
Dry wt, gm					
0	1.6	1.7	1.8	2.1	1.8b*
20	1.9	1.9	1.8	2.2	2.0ab
800	1.7	1.9	2.1	2.2	2.0ab
1600	2.0	1.9	2.2	2.4	2.1a
4800	2.0	1.5	1.5	2.0	1.8b
8000	1.5	1.3	1.2	1.2	1.3c
10,000	0.7	0.7	1.2	1.1	0.9d
12,000	0.9	0.7	0.9	0.8	0.8de
14,000	0.7	0.5	0.4	0.7	0.6e

*Means followed by the same letter are not significantly different at the 5% level.

TABLE 18

Yield of Corn Grown on Davidson Clay Loam as Affected
by Applications of Detergent Tx

<u>Detergent concentration, ppm</u>	<u>Replication</u>				<u>Avg.</u>
	<u>I</u>	<u>II</u>	<u>III</u>	<u>IV</u>	
	<u>Dry wt, gm</u>				
0	1.6	1.7	1.8	2.1	1.8c*
20	1.7	1.7	1.7	1.8	1.7c
800	2.1	2.7	2.2	2.5	2.4b
1600	2.5	3.4	3.2	3.6	3.2a
4800	2.7	3.4	2.7	3.0	3.0a
8000	2.0	2.4	2.1	2.4	2.2b
10,000	1.6	1.5	1.2	1.3	1.4c
12,000	1.9	1.0	0.9	1.6	1.4c
14,000	1.0	0.7	0.7	1.0	0.9d

*Means followed by the same letter are not significantly different at the 5% level.

TABLE 19

Yield of Corn Grown on Norfolk Fine Sandy Loam as
Affected by Applications of Detergent Bz

Detergent concentration, ppm	Replication				Avg.
	I	II	III	IV	
	Dry wt, gm,				
0	2.0	2.0	2.4	2.1	2.1a*
20	2.2	2.6	2.4	2.3	2.4a
800	1.6	2.1	2.4	2.5	2.2a
1600	1.2	1.8	1.8	2.0	1.7b
4800	0.8	0.7	0.9	0.7	0.8c
8000	0.4	0.5	0.3	0.4	0.4d
10,000	0.3	0.3	0.6	0.3	0.4de
12,000	0.09	0.02	0.18	0.13	0.11e
14,000	0.03	0.10	0.09	0.10	0.08e

*Means followed by the same letter are not significantly different at the 5% level.

TABLE 20

Yield of Corn Grown on Norfolk Fine Sandy Loam as
Affected by Applications of Detergent Tx

Detergent concentration, ppm	Replication				Avg.
	I	II	III	IV	
	Dry wt, gm				
0	2.0	2.0	2.4	2.1	2.1b*
20	1.8	1.9	2.5	2.4	2.2b
800	2.2	2.3	2.4	2.6	2.4a
1600	2.2	2.0	2.3	2.2	2.2ab
4800	0.9	1.0	1.0	1.3	1.1c
8000	0.5	0.3	0.5	0.6	0.5d
10,000	0.3	0.3	0.3	0.3	0.3de
12,000	0.09	0.20	0.10	0.20	0.15ef
14,000	0.10	0.00	0.19	0.05	0.09f

*Means followed by the same letter are not significantly different at the 5% level.

TABLE 21

Height of Corn Grown on Two Soils as Affected by Detergent Applications*

Detergent concentration, ppm	Davidson cl		Norfolk fsl	
	Bz	Tx	Bz	Tx
	cm			
0	7.6ab**	7.6c**	8.2a**	8.2b**
20	7.7ab	7.4c	8.9a	8.8ab
800	7.6ab	8.9b	8.6a	9.1a
1600	8.4a	10.2a	7.4b	8.8ab
4800	7.0b	9.4ab	4.0c	5.1c
8000	5.8c	7.4c	2.6d	2.9d
10,000	4.4d	6.3d	1.9de	2.1e
12,000	4.4d	5.5e	1.1ef	1.1f
14,000	3.6e	4.6f	1.0f	0.6f

* Means of four replications.

** Means followed by the same letter are not significantly different at the 5% level.

TABLE 22

Fresh Weight of Corn Grown on Two Soils as
Affected by Detergent Applications*

Detergent concentration, ppm	Davidson cl		Norfolk fsl	
	Bz	Tx	Bz	Tx
0	19.2b**	19.2d**	22.0a**	22.0b**
20	20.9ab	18.4d	23.9a	23.9b
800	20.6ab	28.8c	22.7a	26.7a
1600	23.8a	41.6a	16.7b	23.2b
4800	19.1b	29.2b	6.4c	9.5c
8000	14.6c	26.4c	2.9d	3.8d
10,000	9.7d	16.3de	1.8d	2.8de
12,000	8.2de	12.7ef	0.6d	0.7de
14,000	5.7e	9.1f	0.5d	0.3e

*Means of four replications.

**Means followed by the same letter are not significantly different at the 5% level.



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