TITLE THE HERBICIDAL ACTION OF SODIUM TRICHLOROACETATE WITH SPECIAL REFERENCE TO TRITICUM VULGARE

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THE HERBICIDAL ACTION OF SODIUM TRICHLOROACETATE WITH SPECIAL REFERENCE TO *TRITICUM VULGARE*

By

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INTRODUCTION

In the production of crops it is necessary to wage a continuous battle with weeds. The presence of weeds is undesirable because of their ill effects in the way of competition with the crops for the available food and water supply of the soil. A plant of yellow mustard (Brassica campestris) needs twice the amount of nitrogen and phosphoric acid and four times the amount of potash and water as does the mature oat plant (57). Consequently when one factor becomes limiting the others can not be used effectively; thus the yield of the crop is affected. It has been estimated (13) that in the United States, the yield of corn is reduced as much as ten percent by the presence of weeds. The total annual loss in the United States from weeds exceeds the combined losses due to livestock disease, plant diseases and insect pests (57).

It has been suggested that plants produce toxins in the soil which may affect the growth of the adjacent plants. Such a theory, if proved true, might furnish an explanation for the ecological plant associations as well as information for the detrimental effects of certain weeds on crops.

The commonly used systems of cultivation are usually sufficient to suppress weed growth. The operation, however, is most effective in seed beds and during the early stages of the crop growth. Weeds are usually most harmful during this stage of crop growth (59). Hoeing is another standard measure which can be used successfully with many shallow rooted and garden crops.

In certain cases, for example, as is the case with charlock (Brassica sinapis) in cereal crops, where weeds propagate by seeds, the crop is harvested earlier than the ripening time of the weed seeds. Automatic weed control is thus obtained by normal cultural methods. However, in certain cases such cultural means of control are not possible.

Present agricultural practices, while embracing these old and efficient methods of crop production should include certain chemical weed control measures. The shortage of labor required in the mechanical methods of weed control has given further impetus to the development of chemical methods which can be used successfully for weed control purposes.

During the last decade, among many other chemicals, acid arsenical spray, carbon disulphide, sodium chlorate, sulphuric acid, 2,4-dichlorophenoxyacetic acid (2,4-D) have been employed with varying degrees of success for the control of annual, biennial and perennial weeds. None of the chemicals gave entirely satisfactory results with annual or perennial grasses. Only recently sodium trichloroacetate (TCA) has come to the front as a useful herbicide in this respect.

Recommendations regarding the application and dosages involved have stimulated much interest among the farmers. They wish to know how long the herbicide persists in the soil and to what extent it is affected by the chemical and physical nature of the soil.

From the point of view of the horticulturist, this information is important in order that he may modify cultural practices so that subsequent plantings may not be affected adversely. Moreover, in the case of pre-planting or pre-emergence treatment this information would serve an a useful index in regulating the dosage of the herbicide in relation to environmental factors and other situations which may demand consideration in crop rotation.

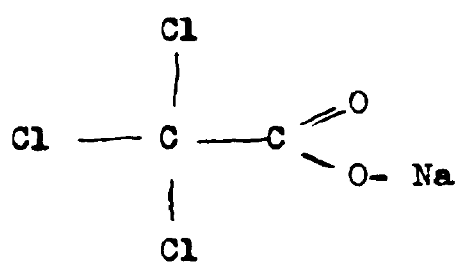
The purpose of this investigation was to attempt to answer certain of these questions dealing with the use of TCA as a herbicide.

REVIEW OF LITERATURE

1. General

Plant growth is influenced by environmental conditions. A minor change in one sometimes starts a series of complex reactions which seriously affect the development of the plant.

The sodium salt of trichloroacetic acid is a fairly stable compound and when certain concentrations are present in the root zone it will kill plants. Molecular weight of the compound is 185.37 and the structural formula is given below:-



A search of literature reveals little information pertaining directly to the herbicidal effects of TCA on wheat (<u>Triticum vulgare</u>). However, an attempt is made here to present the review of results which have direct or indirect bearing on the subject.

The most comprehensive work of this nature is given in the reports of Weed Control Research Committees. The related references are included in this manuscript.

The grass killing properties of trichloroacetates were established as early as 1949 (47). Sodium trichloroacetate, abbreviated as TCA in this discourse, has given satisfactory results for the control of grass weeds (8, 17, 22) and, by contact, broad-leaved weeds as well (47). It caused a severe stunting in Russian thistle (Salsola kali) and red root pigweed (Amaranthus retroflexus) (22) and inhibited the growth of many other plants (36).

It has been found that the soil, atmospheric conditions, variety or species of the weed plants, and their stage of growth influence the rate of the herbicidal action of TCA (3, 4, 81). However, the rates of applications for different environmental conditions are not established as yet.

The experiments, concerning TCA treatments on quack grass, have shown that the percentage of kill was proportional to the rate of application of TCA (32, 34, 35, 38, 40, 41, 42, 43, 53, 80, 81). However, heavier rates of application were required to produce a complete kill (35, 55, 66). No resprouting was observed at any application of 150 pounds per acre (8, 20, 35).

Friesen (22) applied 20, 40, 80, 100 and 160 pounds per acre, TCA prior to heading of the grass. All rates of application killed the top growth of the grass. However, root kill was incomplete (22, 27, 35, 66). There was a 5 to 15 percent recovery, depending upon the rate of application, in almost all treatments after a period of 8 weeks. These results were further corroborated by Pavlychenko (54, 55) and Slife and Fuelleman (65) who used different amounts of the chemical in their experiments.

In another series of experiments McDonald et al. (39, 40, 41, 42, 45) obtained inconsistent results when they applied 10, 20, 30, 40, 60 and 80 pounds of TCA in 32 1/2 gallons of water per acre. The spray applications were made during the second week of June under similar condition that is, nature of soil, soil moisture and stage of grass development were practically the same in all the cases.

Soil sterility caused by application of TCA appeared to be temporary. Crops such as oats, alfalfa (33) and corn (75) grew normally on the treated plots. The toxic conditions of the soil lasted only for 60 to 90 days (47).

Experiments (80) showed that soil moisture had a greater significance, within the range of applications used, than did the actual rate or date of application. In another series of the experiments high moisture content of the soil led to inferior results (5, 19). However, best results were obtained on a moderately dry soil with scant to moderate rainfall during a one month period following the spray (5). Watson (74) found a direct correlation between rainfall following spray and degree of quack grass control. It was further pointed out by him that sufficient rainfall, following soil application of the chemical, was necessary to get the material into the root zone.

Tillage operations when combined with TCA treatments gave a better control of weeds (9, 19, 65). However, Chadwick et al. (15) did not find any such evidence from their experiments. Watson (74) found plowing with a mold-board plow prior to TCA treatments greatly enhanced the effectiveness of the chemical and proved to be a good effective treatment in quack grass control. In another series of experiments such cultural operations made up for low rates of TCA applications (6, 11, 14, 36).

Barrons and Watson (5) further suggested that during a period of low carbohydrate content the grasses are more easily controlled. Treatments at this stage may be combined with tillage for the best results.

In another series of experiments McCall and Zahnley (48) applied 50, 75, 100 and 200 pounds of TCA in 109, 218 and 436 gallons of water per acre; the latter application proved to be more effective because of the soil penetration by larger volumes of water. The volume differences were most notable at 50 pounds per acre application which might be a border line for grass control. They further suggested that there was practically no difference in results with ammonium or sodium salts of trichloroacetic acid (46, 48).

Livestock did not show any aversion to the sprayed vegetation (24). Alfalfa sprayed with 120 pounds per acre made a vigorous regrowth but at the end of six weeks began to die and appeared to be completely killed (24).

Crop tolerance studies made by Barrons (4) might be useful in devising pre- and post-emergence treatments of TCA. His observations are summarized as follows:

Tolerant group, not effected at 5 or 10 pounds per acre and which showed apparent recovery from 20 pounds, included crops such as peas, lettuce, tomato, pepper, egg plant, tobacco, carrot, parsnip, celery, cabbage, kale, cauliflower, turnip, broccoli, mustard, radish, flax, beet and swiss chard.

Intermediate group, showed no appreciable effect at 5 pounds and were apparently recovered from any effect noted at 10 pounds, included crops such as alfalfa, Ladino clover, oats, cotton, okra, asparagus, gladiolus, sweet potato, onion, spinach, potato, strawberry, muskmelon, cucumber, pumpkin, squash, watermelon, and peanut.

Susceptible group, showed a marked effect at 5 pounds and severe or higher rates, included crops such as bean, lima bean, soybean, sweet clover, alsike clover, Korean lespedeza, corn, sorghum, sudan grass, Kentucky blue grass, seaside bent grass, red top grass, German millet, timothy, orchard grass, rice, rye, barley and wheat.

2. Mode of TCA Entry into the Plant

Review of literature does not lead to any conclusive information on this point. Plowing prior to the application of TCA has proved to be an efficient method in quack grass control (11, 21, 76) which might suggest that roots serve as an important avenue to the entry of the compound. Further support of this assumption comes from experiments in which a better kill was obtained in up-turned quackgrass sod than when the foliage was sprayed (6). No systemic TCA response was noticed when primary leaves of kidney beans were dipped in TCA solutions (7).

The physiological action of TCA on plants is not well understood. It is stated that trichloroacetates, when applied to soils, are absorbed by the roots (1) and are carried to all parts of the plant through the xylem which is mainly a dead tissue. The rate of translocation is slow, however, in case of foliage application as the phloem, tissue involved in such translocation is killed (1).

3. Pre- and Post-Emergence Treatments.

Pre-emergence treatments have aroused considerable interest because they are the only type of treatments, thus far developed, which control both broad-leaved annuals and weedy grasses such as crabgrass and foxtail (78). Here, however, one is primarily interested in the elimination of undesirable effects rather than eradication or a high percentage kill of the weeds. Such soil treatments with TCA prevent emergence of grass seedlings and thereby help in conservation of soil resources that can be used advantageously by the crops.

Sufficiently favorable results were obtained to warrant the belief that TCA can be used successfully with certain crops e.g., pea, tobacco, beet, eggplant, tomato, pepper, and flax (4). However, it is not certain with which crops pre-planting or post-planting treatments should be used. The safe rates and methods of application in relation to environments have not yet been established.

Pre-emergence treatments with TCA were impossible on soybeans and proved to be injurious to crucifers (79) and onions (52) even at the low rate of 4 pounds. All corn plants were killed at 10, 20, and 30 pounds per acre (67). Rates higher than 20 pounds severly injured beets (25, 26) but weed control was good (28, 70).

Forty pounds of TCA, as immediated post-emergence treatment to flax, proved to be of marginal utility in control of gree foxtail (16) and wild oats (58). At low rates of 2, 4, 8 and 12 pounds acid equivalent, there was no injury to flax (18, 12). The yield of flax was lowered significantly at 20 pounds (33). There was no control of the wild oats growing in the flax plants treated with 40 pounds; the flax showed signs of injury after 20 days from the date of seeding (16). The surviving plants on the treated plots, at the time of harvest, were 6 to 7 inches shorter, and sickly in appearance, in comparison to plants on check plots (16).

<u>Setaria</u> <u>Sp</u>. in flax seemed to be easily susceptible to TCA application. Five to 10 pounds of TCA in 10 to 20 gallons of water gave good

control of weeds without injury to flax (37, 44). Higher rates reduced flax yields and did not result in effective control of grassy weeds (31). In another experiment, 4 pounds TCA in 50 gallons of water resulted in 85 percent control of crabgrass (72) in Alaska peas.

Warren and Singletary (73) found that 44 pounds of TCA gave good control of weeds without lowering the yields of direct-seeded tomatoes. In another experiment the yield of Alaska peas was not affected by use of TCA at rates up to 8 pounds per acre.(10). On the other hand, the yield of Yellow Jersey sweet potatoes was reduced signigicantly by 2 to 4 pounds of TCA when applied in 50 gallons of water (72), the control of crabgrass in the crop was 85 percent.

MATERIALS AND METHODS

Soil conditions play an important role in the determination of the satisfactory agricultural practices which are to be followed after the application of the herbicide. In order to determine the residual effects of TCA in relation to crop growth on different types of soils, an experiment in a split plot design, was arranged at the Plant Science Green House, Michigan State College, East Lansing, Michigan.

Equal volumes of soils- Oshtemo sand, Brookston clay loam and muck weighing 4,000 grams, 3,700 grams and 1,700 grams respectively, were mixed with amounts of TCA corresponding to the rates of 15, 30 and 60 pounds per acre and placed in number 10 cans. The calculations were based on the surface area of the cans and rates are expressed on the acid equivalent basis. The mixing operations were done on 21, 42, 64 and 108 days before the sowing date of the crop.

Wheat was used as a test plant as it is known to have sensitivity to TCA at rates as low as 5 pounds per acre (4). The cultures were seeded to Henry spring wheat on July 9, 1950; 20 seeds were placed in each can at a depth of 1/2 to 1 inch.

To each can of Oshtemo sand was added 500 ml. of distilled water. Each can of clay loam and muck soil recieved 700 ml. of water. These quantities of water were considered to be enough to raise the moisture levels of the soils to their optimum moisture-holding capacities.

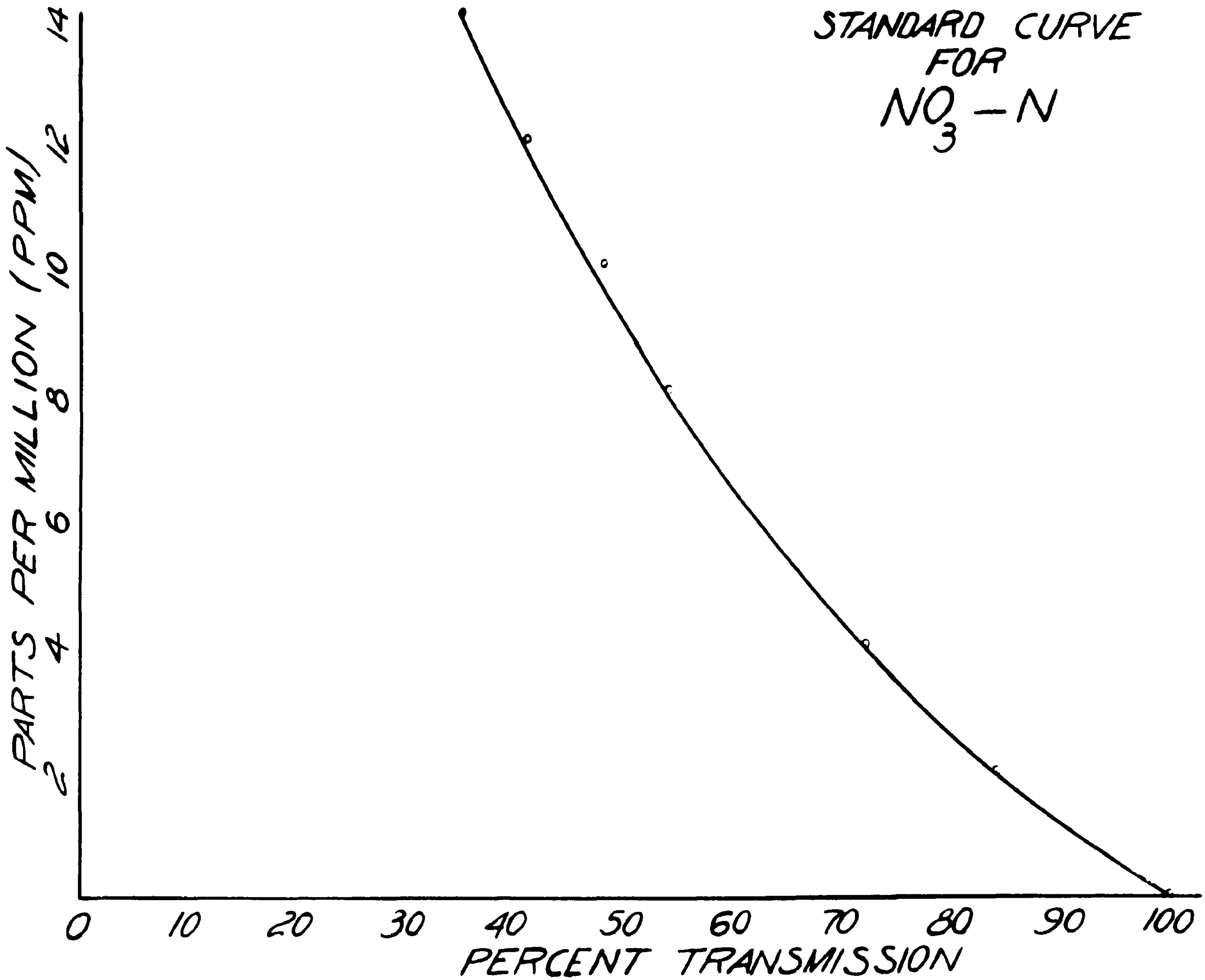
During the entire period of the experiment the cans were weighed frequently. Sufficient water was added to each pot to bring the moisture content back to its original level. The losses of water were due to the surface evaporation and transpiration by wheat plants. There was no loss because of leaching as the cans were water-tight.

In order to find the relationship, if any, between TCA applications to soils and their nutrient status, the soil samples were taken by a specially designed soil sampling tube which was inserted to the bottom of the cans. These samples were taken on April 4, April 18, May 2, May 16, June 21, and August 23, 1950 and were dried in an oven at 60° C. Lots of 12, 40, and 50 grams of each treatment were put aside each time for soil analysis work. Quantities of soils in excess of those needed for analysis were put back into the respective cans. Determination of pH and mineral nutrient levels were made.

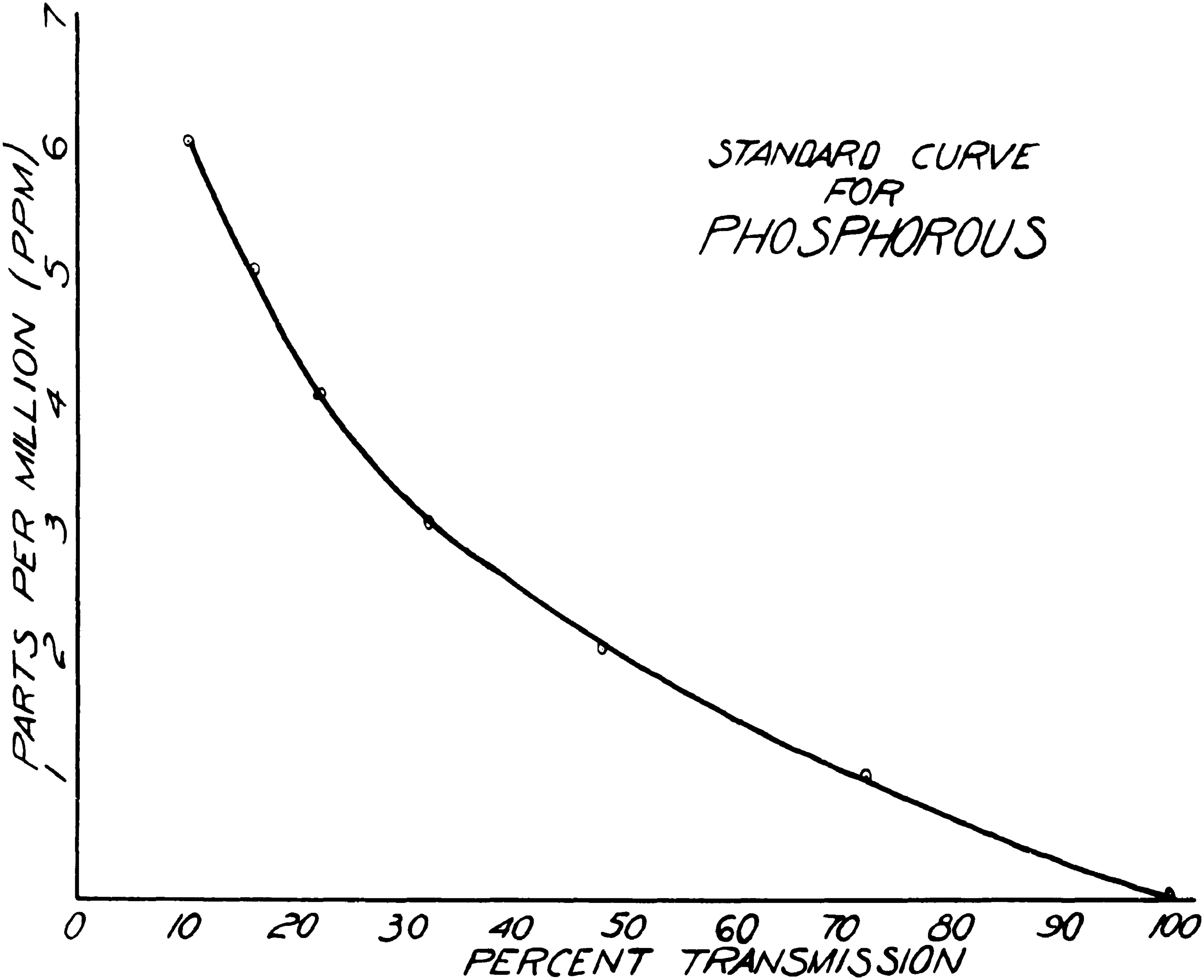
The pH of the soil samples was determined by the pH meter. Nitrate nitrogen and available phosphorus and potassium determinations were made by a revised Spurway method which makes use of a colorimeter. Calcium, magnesium, ammonia and nitrite nitrogen were determined by the standard Spurway methods (68).

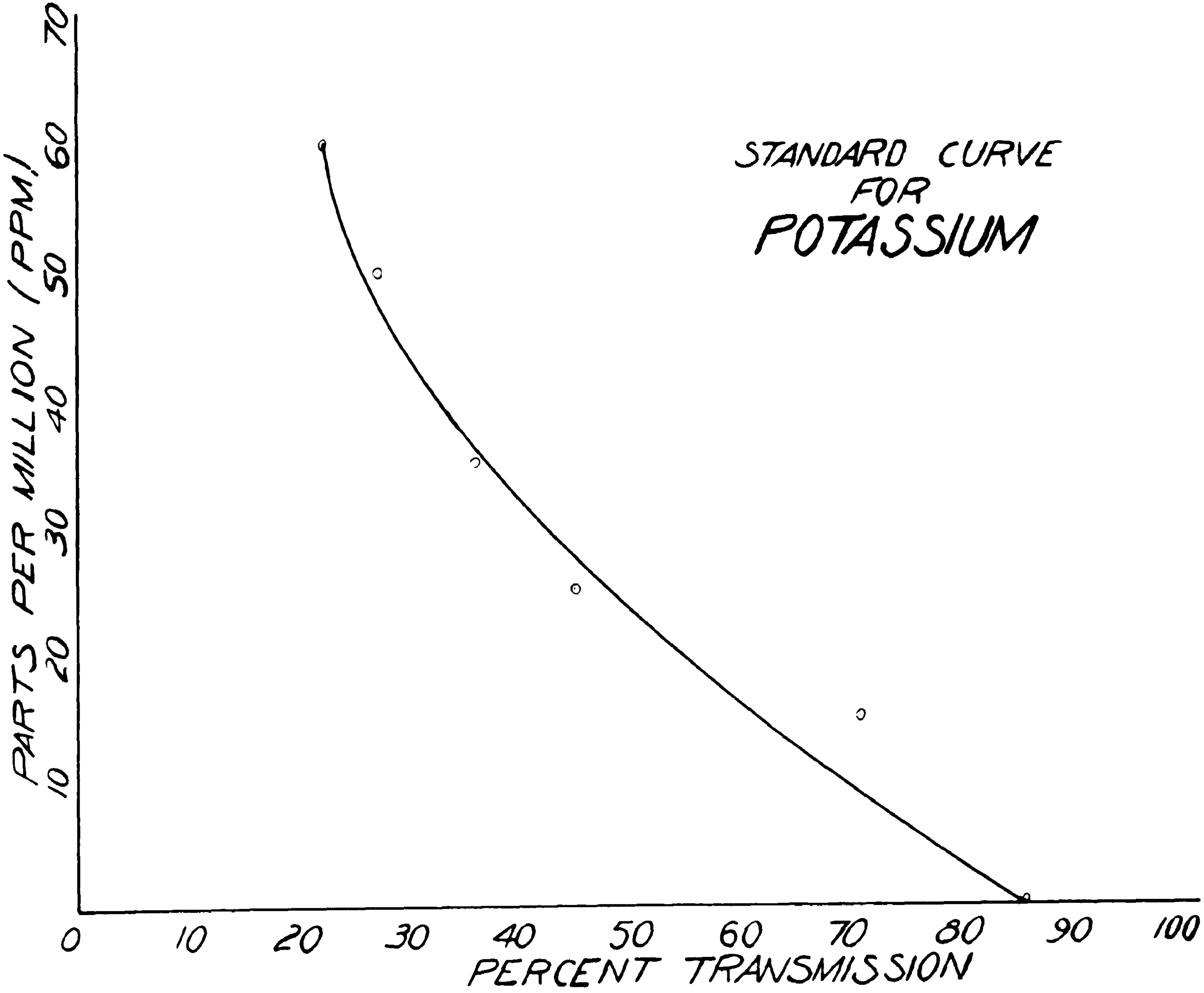
In making use of the colorimetric procedures, the standard curves, given on pages 13, 14, and 15, for N, P, and K, were constructed. The values of unknown soil solutions were determined from these standard curves. The data, averaged for all dates of sampling, are presented in Table 6.

Plant growth was considered to be a direct measure of toxicity of the compounds (57). With this in mind the data were recorded for rate of growth, fresh weight of the tops, dry weight of the tops and dry weight of the roots. The data are given in Tables 1, 2 and 3. The rate of growth is shown by Figures 1, 2 and 3.



STANDARD CURVE
FOR
$NO_3 - N$
PARTS PER MILLION (PPM)
2
4
6
8
10
12
14
0
10
20
30
40
50
60
70
80
90
100
PERCENT TRANSMISSION


STANDARD CURVE
FOR
PHOSPHOROUS
PARTS PER MILLION (PPM)
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90
100
PERCENT TRANSMISSION



STANDARD CURVE
FOR
POTASSIUM
PARTS PER MILLION (PPM)
10
20
30
40
50
60
70
0
10
20
30
40
50
60
70
80
90
100
PERCENT TRANSMISSION

The main crop was harvested on August 23, 1950. The plants growing in soils which recieved the largest applications of TCA just 21 days before the sowing of the crop were harvested earlier as they would have been dead by August 23.

The second series of the experiments were designed to confirm the theory that the death of the plants which had been injured by TCA was due to unbalanced nutrient uptake. In this case, 15 and 30 pounds per acre applications were made on Oshtemo sand only. The corresponding amounts of TCA, size of the cans, mixing operations and moisture level conditions were the same as given in the preceeding pages. However, N-P-K treatments were included in the experiment. The fertilizer was furnished by applying 1.6 grams of a mixture of ammonium sulfate, superphosphate and muriate of potash mixed in such a way as to make a 10-10-10- fertilizer. The mixture was added as a band application, at the outer edge of the soil surface, just prior to the date of sowing which was March 9, 1951 in this case.

The crop was harvested on April 6, 1951. The soil samples were taken and were analyzed for pH, N, P and K in the manner described in the preceding pages.

The plant tissue was analyzed for total nitrogen and phosphorus by methods given in methods of analysis, A.O.A.C. (3). Potassium was determined by the Flame Photometer using lithium as the internal standard. The data are given in Table 7.

Another experiment was arranged to determine the effect of TCA upon the metabolism of plants. Seeds of spring wheat (var. Henry) were selected for maturity and planted in flats, containing 8,000 grams of Oshtemo sand.

The flats were lined with oil paper to prevent leaching. Each flat contained 400 plants. Two replications of 2,000 plants each were used from which to obtain material of the treated and non-treated plants.

Applications of TCA (70%) - at the rate of 30 pounds, acid equivalent, per acre were made to the soil prior to the sowing of the seeds. The pH of the soil was adjusted to 6.5 by the addition of lime. The application of TCA did not appreciably change the pH of the sand. The soil was maintained at its water holding capacity for the duration of the experiment. The flats were placed in a greenhouse at temperatures ranging from 70° - 75° F. during the day and 65° F. at night. The plants were harvested fourteen days after sowing. The plant material was dried in the dark at 30° C. for seventy-two hours and then segregated into root and leaf (including stem) tissue. After drying, the material was ground to pass a 60 mesh sieve and stored in glass jars until needed.

Amino acids were determined microbiologically with the organisms Lactobacillus arabinosus, Streptococcus faecalis and Leuconostic mesenteroides. The media used in the various determinations were essentially the same as those described by Sauberlich and Baumann (60). Samples were prepared for assay by the method described by Stokes et.al. (69) with the exception of the tryptophane samples which were prepared according to the method of Wooley and Sebrell (82). Carbohydrates were determined by the procedure outlined by Sell et al. (61). The method of analysis for netrogen and ether extract were those given in A.O.A.C. (2).

Respiration Studies:-

The rate of oxygen uptake was determined in a standard Warburg apparatus in 0.02 M pH 5.7 phosphate buffer (64, 71).

The treatments considered are tabulated in Table 12. In experiment 1, TCA (70%) at the rate of 30 pounds per acre acid equivalent, was mixed thoroughly with 8,000 grams of Oshtemo sand. The treated soil was transferred to wooden trays lined with oil paper to prevent leaching. Seeds of Henry spring wheat were sown in the wooden trays on July 18, 1951 and the crop was harvested to the ground level after 10 days.

In experiment 2 and 3 (Table 12) 4 week old cauliflower, tomato, sugar beet and bean plants were completely saturated with a 5,000 ppm TCA spray. The respiration studies were conducted on these plants in the 3rd week of July, 1951. The plants were 5 weeks old at this time. A sample of 1 sq. cm. in area was taken from the central portion, along the mid-rib, of the treated and untreated leaves.

In experiment 4 (Table 12) one gram of 3-p-chlorophenyl 1,1-dimethylurea (CMU) was dissolved in absolute alcohol and volume was made up to 100 ml. with distilled water; 5 ml. of this solution was further diluted to 100 ml. thus giving 500 ppm of the compound. The same procedure was adopted for isopropyl N-phenylcarbamate (IPC) which was also insoluble in water.

These solutions were employed to moisten the filter papers placed at the bottom of the Petri-dishes. During the entire period of the experiment uniform moisture conditions were maintained. Each Petri-dish contained 50 wheat seeds (var. Henry). Respiration studies were made on these seeds.

The same procedure was adopted in experiment 5 (Table 12), with the exception that the solutions concentrations of TCA were different in this

EXPERIMENTAL RESULTS

Yield

The effect of sodium trichloroacetate on the growth of wheat plants is shown by the data in Tables 1, 2 and 3. It is clear from the recorded observations that the amount of growth, recorded as fresh weight of tops, dry weight of tops and dry weight of roots, was directly related to the amounts of TCA applied. For instance, the fresh top-growth, where wheat was planted on muck soil 21 days after TCA was applied at the rate of 60 pounds per acre, amounted to 0.46 grams per pot as compared to 1.50 grams per pot where the rate was 15 pounds per acre and 14.00 grams per pot where the chemical was not applied. Similar results were obtained where TCA was applied on clay loam and sandy soils where the elapsed time between treatment and planting was 21 days.

The residual effect of TCA was less in the sandy soil than it was on the muck and clay loam. This is shown by the results obtained when the elapsed time between treating with TCA and planting of wheat was 42 days. In the case of sand, where 15 pounds per acre of the chemical was applied, the wheat was not appreciably injured and only slight injury resulted where the applications were 30 pounds per acre. At 60 pounds per acre application wheat yields were reduced from an average of 19.33 grams to 10.66 grams per pot. In contrast to the results obtained in the sandy soil all applications of TCA on clay loam and muck soils caused pronounced injury to wheat plants where the elapsed time between application of TCA and planting of wheat was 42 days.

Where the elapsed time between treatment and planting was 64 days the results show that wheat grown on the sandy and clay loam soils was not injured when the applications of TCA were as high as 60 pounds per acre. On the other hand the residual effect of TCA was quite pronounced on the muck soil even 108 days after application of the chemical.

The growth rate curves shown in Figures 1, 2 and 3 show graphically the variations which existed in the results obtained from different soils. It may be seen from Figure 1 that on muck soil 15 pounds of TCA per acre significantly affected growth where the elapsed time was 21 or 42 days but had little effect where more than 42 days elapsed. Where the rate of application was higher, 30 or 60 pounds per acre, growth was affected even when 108 days had elapsed.

It can be seen from the curves representing the plant growth rate for clay loam soil, Figure 2, that the growth of wheat was not depressed in the pots where planting had occurred 64 or 108 days after the application of 15, 30 or 60 pounds TCA per acre. The growth curves for these time periods are almost identical with those for the controls, thus indicating quite clearly that the toxic or residual effect disappeared after 64 days from the time of application. The depression of growth was pronounced only where planting was done 21 or 42 days after the chemical was applied.

The effect of TCA application on sandy soil can be seen in Figure 3. This shows that growth was only depressed by the 15 pound rate of TCA application where the elapsed time period was 21 days. No appreciable depression of growth was observed at the lower rate where the elapsed time period was longer than 21 days. For the two heavier rates, depression of growth occurred where elapsed time was either 21 or 42 days.

The plants in Figures 4 and 5 show the effect which TCA application to the soils had on the growth of wheat plants. Figure 4 shows the contrast between the plants grown in untreated muck and plants grown in muck treated with TCA where the elapsed time, after application, was 108 days. A similar growth trend for the plants grown on clay loam soil (S_2) can be seen where the elapsed period after application was 21 or 42 days in contrast to two longer periods of 64 and 108 days. It may also be observed from Figure 4 that plants grown in sandy soil show a marked contrast between control plants and treated plants where the elapsed time, after application, was only 21 days.

Figure 5 shows the same relative differences as shown in Figure 4 with the exception that the picture was taken 30 days after planting instead of 20 days, as was the case in Figure 4. The results are somewhat more striking.

The data recorded, in Tables 1, 2 and 3, show that the dry weight of the tops would lead to exactly the same conclusions as have been drawn from fresh weight of tops. Some inconsistencies do exist in the root weights. The data indicate, however, that the inconsistencies are the results of experimental errors. For instance, the dry weight yield of wheat plants was greater from 30 pounds per acre application of TCA than from 15 pounds on the sandy soil where the time interval was 42 days. The same thing occurred on muck soil where the time interval was 64 days. Such results were probably due to loss of roots in the washing process or to the fact that some soil may have remained on some of the roots.

In general, the conclusions to be drawn from the dry root weights are not unlike those already discussed for the fresh top yields.

The analysis of variance presented in Table 4 shows that highly significant differences occurred between times (elapsed time from the date of application to the date of planting), rates of applications, and soils. It is interesting that second and third interactions are also significant. For instance, consider times and soils. The injurious effects of TCA disappeared sooner in the sandy soil than in either of the other two soils and lasted longer in the muck. Some injurious effect persisted in the muck even to 108 days.

One would expect the interaction between rates and times to be significant. Such was the case, particularly on the two mineral soils.

The significance of the soils and rates interaction is explained by the fact that rates made more difference, in the 21 days time interval, in the sandy soil than in the other two soils. In the clay loam and muck the three treatment rates, 15, 30 and 60 pounds per acre applications, produced results which were similar and of greater magnitude than those obtained in the sand. On the other hand when final time is considered, the opposite is true. Sixty pounds of the chemical still caused a pronounced injury in the muck soil but 15 pounds per acre application was not injurious. With the other soils, at that time interval, none of the applications were injurious.

By referring to Table 5 it is possible to see the effects of rates, times, and soils. In each case the other variables are averaged. For all times of application and all soils, significant differences in the fresh weight of the tops but not in the dry weight of tops resulted from all rates of treatments.

A consideration of time, including all rates and soils, shows that significant differences resulted in all three yield categories. Likewise, the same was true of the differences caused by soils when all times and rates were thrown together.

Soil Nutrients

The data presented in Table 6 indicate that the nutritional status of soils, including pH, and amount of available N, P, K, Ca, Mg, NH_4 and NO_2 was not affected by the different treatments considered in this investigation. In many instances, the results varied more widely between replicates than between treatments. Furthermore, the differences were not consistent with the time. For instance, where the time was 21 days (T_1) the nitrate content of soil S_1 (muck) seemed to increase with rate. Such was not the case, however, where longer time was involved nor did it hold for soils 2 and 3. Similar instances could be pointed out for other constituents. The potassium content of the soil 3 (Oshtemo) seemed also to increase with the rate of application of TCA for the 21 days time interval but did not so increase where longer time was involved. The other soils did not behave as did Oshtemo.

However, differences in nutrient contents of the soils can be considered natural due to differences in the nature of the soils. Tests indicated that P, NH_4 and NO_2 were present only in traces in all the soils used in this experiment. For that reason, the results are not presented.

During the progress of this study an experiment was set up to determine the effect of fertilizer on the action of TCA. Wheat was grown in Oshtemo soil. Treatments included a control and two rates of TCA, 15 and 30 pounds per acre applications, with and without 10-10-10 fertilizer.

The data presented in Table 7 show that fertilizers increased the NO_3, P and K content of the control soil and total N and K content of the plants but did not increase the phosphorus content of the plants. Nitrates were increased to high levels on the TCA treated soils which caused a considerable increase in the total nitrogen content of plants from TCA treated soil. Such plants showed an arrested growth indicating some interference in the metabolic activities of the plants. Thus the plants could not use the nitrate nitrogen present in them. However, potassium in the plants did not increase when the plants were stunted by the TCA treatments. On the contrary there was a marked decrease in the potassium content of the injured plants.

Metabolism of the Plants

Wheat plants in TCA treated soil showed marked metabolic changes as can be seen from Tables 8, 9, 10 and 11. Each entry is recorded as a single determination on each replicate.

The data in Table 8, expressed as percent amino acid in the sample, show the following trends: The leaf tissue of the treated plants contained more protein and arginine than that of the controls. The percentage of tryptophane was less in the treated plants. Slight differences were noted for methionine, lysine, valine, leucine, histidine, and phenylalanine. The percentage of isoleucine and threonine did not change.

Expressing the data in Table 8 as percent of amino acids in crude protein, a somewhat different pattern was observed. The leaf tissue of the treated plants contained slightly less lysine, valine, leucine, histidine, phenylalanine, isoleucine, threonine and tryptophane than did the controls. Approximately the same percentage of methionine and arginine was observed in both treated and non-treated tissue.

The data presented on the basis of percentage of protein in the sample indicate that there is an accumulation of protein. The differences in amino acids are not as pronounced as was noted in the tissue treated with 2,4-D (62, 77). The results expressed as percent amino acid in the crude protein suggest that the nature of the protein has changed since the percentage of amino acids are as a rule less in the treated tissue than in the controls. This would indicate that the TCA has an effect on proteolytic enzymes.

The data presented in Table 9 show only a slight increase in the percentage of protein and amino acid in the root tissue of the treated plants. When expressed as percentage of the crude protein, little difference was observed in most of the amino acids with the exception of histidine which was slightly greater in the treated samples.

The data expressed in Table 10 show a slight increase in the percentage of reducing sugar and acid hydrolyzable polysaccharides in the leaves of the treated wheat plants. However, a tremendous decrease was noted in the percentage of non-reducing sugar, ether extract, unsaponifiable material and fatty acids. A slight difference was observed in the percentage of starch.

In the root tissue (Table 11) of the wheat plants there was a higher percentage of reducing sugar and starch in the treated plants. Little difference was noted in the percentage of the non-reducing sugar and ether extract in both the treated and non-treated plants. Only slight reduction was observed in the acid hydrolyzable polysaccharide of the treated plants.

The large increase of the reducing sugar and starch in the root tissue and the accumulation of protein in the leaf and root tissue of the TCA treated plants suggests that the large depletion of the percentage of non-reducing sugar in the leaves is due to the conversion of part of the sugar to protein and to translocation of the remainder to the root tissue, in the form of reducing sugar, where it is stored as starch.

Respiration Studies

The application of TCA to soil and foliage caused an increase in the respiration rate of plant tissue. The data reported in Table 12 show that wheat seeds showed the greatest respiration activities during the first 24 to 48 hours after which the rate became slower. The experiment also indicated that 3-p-chlorophenyl 1,1-dimethylurea (CMU), isopropyl phenylcarbamate (IPC) and sodium salt of 3,6-endoxohexahydro phthallic acid (Endothal) were inhibitory to respiration more than TCA. Foliage treatments with 5,000 ppm solution produced results in treated plant species. Sugar beet was most tolerant followed by tomato and cauliflower while beans were least tolerant.

Table 1

The residual effects of soil applications of sodium trichloroacetate on the yield, fresh and dry weight of tops and dry weight of roots, of wheat grown on muck soil.

Treatment	Yield per pot in grams*		
	Fresh wt. of tops	Dry wt. of tops	Dry wt. of roots
Time 1 (applied 21 days before planting)			
15 lbs TCA	1.50	0.36	0.47
30 lbs TCA	0.70	0.33	0.30
60 lbs TCA	0.46	0.13	0.27
Control	14.00	4.53	1.23
Time 2 (applied 42 days before planting)			
15 lbs TCA	3.33	0.76	0.60
30 lbs TCA	3.33	0.46	0.40
60 lbs TCA	0.93	0.23	0.23
Control	11.00	2.96	0.67
Time 3 (applied 64 days before planting)			
15 lbs TCA	12.00	3.06	0.60
30 lbs TCA	10.66	2.30	1.07
60 lbs TCA	9.00	2.10	0.63
Control	12.00	2.90	1.10
Time 4 (applied 108 days before planting)			
15 lbs TCA	12.33	3.13	0.87
30 lbs TCA	10.66	2.86	0.93
60 lbs TCA	9.66	2.76	1.13
Control	12.66	3.63	1.13

* Average of three replications.

Table 2

The residual effects of soil applications of sodium trichloroacetate on the yield, fresh and dry weight of tops and dry weight of roots, of wheat grown on clay loam soil.

Treatment	Yield per pot in grams*		
	Fresh wt. of tops	Dry wt. of tops	Dry wt. of roots
Time 1 (applied 21 days before planting)			
15 lbs TCA	2.00	0.93	0.43
30 lbs TCA	1.00	0.63	0.20
60 lbs TCA	0.86	0.33	0.17
Control	18.33	4.90	1.17
Time 2 (applied 42 days before planting)			
15 lbs TCA	4.66	1.20	0.67
30 lbs TCA	1.00	0.20	0.27
60 lbs TCA	0.90	0.26	0.10
Control	24.00	6.16	1.90
Time 3 (applied 64 days before planting)			
15 lbs TCA	24.00	6.06	1.70
30 lbs TCA	22.00	5.93	1.50
60 lbs TCA	24.66	6.50	1.30
Control	25.33	7.13	1.73
Time 4 (applied 108 days before planting)			
15 lbs TCA	22.33	5.56	1.50
30 lbs TCA	23.00	6.66	1.40
60 lbs TCA	20.33	5.13	1.47
Control	19.33	4.86	1.30

* Average of three replications.

Table 3

The residual effects of soil applications of sodium trichloro-acetate on the yield, fresh and dry weight of tops and dry weight of roots, of wheat grown on Oshtemo sand.

Treatment	Yield per pot in grams*		
	Fresh wt. of tops	Dry wt. of tops	Dry wt. of roots
Time 1 (applied 21 days before planting)			
15 lbs TCA	4.66	1.46	0.30
30 lbs TCA	2.66	0.63	0.33
60 lbs TCA	1.10	0.40	0.23
Control	18.66	6.83	2.63
Time 2 (applied 42 days before planting)			
15 lbs TCA	18.00	6.66	1.63
30 lbs TCA	16.00	5.46	2.57
60 lbs TCA	10.66	2.30	1.40
Control	19.33	6.86	2.17
Time 3 (applied 64 days before planting)			
15 lbs TCA	24.00	8.23	2.71
30 lbs TCA	26.33	9.10	3.13
60 lbs TCA	22.66	8.30	2.50
Control	24.00	8.06	2.97
Time 4 (applied 108 days before planting)			
15 lbs TCA	23.33	7.23	2.67
30 lbs TCA	26.33	8.30	2.67
60 lbs TCA	23.33	7.40	2.50
Control	21.33	7.30	2.70

* Average of three replications.

Table 4

Analysis of variance of wheat yield, fresh and dry weight of tops and dry weight of roots, in the split plot experiment

		Fresh wt. of tops		Dry wt. of tops		Dry wt. of roots	
Sources of variations	D.F.	S.S.	M.S.	S.S.	M.S.	S.S.	M.S.
Replications	2	17.09	8.54	7.31	3.65	1.24	0.62
Time	3	5269.08	1756.36**	416.50**	138.83**	33.13	11.04*
Error	6	29.64	4.94	17.98	2.99	0.85	0.14
Sub-group (1)	11	5315.81		441.79		35.22	
Soils	2	2461.72	1230.87**	360.13	180.06**	45.61	22.80**
Time x Soils	6	821.16	136.86**	94.96	15.82**	7.56	1.26*
Error	16	237.04	14.81	13.92	0.87	5.32	0.43
Sub-group (2)	35	8835.73		910.80		93.71	
Rates	3	1294.22	431.40**	128.49	42.83**	10.15	3.38**
Rates x Time	9	1351.83	150.20**	130.33	14.48**	7.26	0.80**
Soils x Rates	6	161.47	26.91**	7.27	1.21*	1.87	0.31**
Rates x Time x Soils	18	360.93	20.05**	41.94	2.33**	7.44	0.41**
Error	72	319.60	4.43	30.73	0.42	6.75	0.09
Total	143	12323.78		1249.56		127.18	

* Significant at 5% level.

** Significant at 1% level.

Table 5

A summary of the yield data for all treatments, rates, times and soils.

	Rates- including all times and soils				L.S.D.**	
	R_1	R_2	R_3	R_4	5%	1%
Fresh weight of tops*	12.68	11.98	10.38	18.33	0.977	1.297
Dry weight of tops	0.37	0.36	0.30	0.55	0.299	0.397
Dry weight of roots	1.23	1.23	0.99	1.72	0.140	0.186
	Times- including all rates and soils					
	T_1	T_2	T_3	T_4		
Fresh weight of tops	5.50	9.43	19.72	18.72	1.280	1.384
Dry weight of tops	1.79	2.80	5.81	5.40	0.996	1.509
Dry weight of roots	0.64	1.05	1.79	1.68	0.203	0.307
	Soils- including all times and rates					
	S_1	S_2	S_3			
Fresh weight of tops	7.76	14.62	17.65		1.664	2.292
Dry weight of tops	2.04	3.90	4.05		0.403	0.555
Dry weight of roots	0.76	1.05	2.07		0.276	0.380

* All data expressed in grams per pot.

** Least significant difference

The effects of soil applications of TCA on the nutritional status of the soils during the entire period of the experiment

Treatments		Soil$_1$ (muck)					Soil$_2$ (Clay loam)					Soil$_3$ (Oshtemo sand)				
		pH	NO_3	K	Ca	Mg	pH	NO_3	K	Ca	Mg	pH	NO_3	K	Ca	Mg
T_1	R_1	6.7	11.6	10.0	147.0	5.3	6.6	8.4	4.0	95.0	4.6	6.5	1.8	3.0	63.0	3.7
	R_2	6.6	11.8	10.3	117.0	4.0	6.7	8.0	5.2	106.0	4.0	6.4	2.2	4.2	78.0	3.0
	R_3	6.6	13.7	11.0	113.0	4.3	6.6	7.2	4.3	90.0	3.7	6.6	1.4	5.0	53.0	3.3
	R_4	6.6	16.9	11.0	130.0	4.0	6.6	7.8	5.0	83.0	4.0	6.7	1.1	6.5	53.0	3.3
T_2	R_1	6.5	17.6	10.0	169.0	3.8	6.5	11.2	4.2	78.0	4.2	6.3	3.0	3.7	77.7	2.2
	R_2	6.6	20.4	11.0	169.0	3.8	6.5	13.5	3.3	72.0	3.7	6.5	2.0	4.4	90.0	2.0
	R_3	6.5	21.4	10.6	160.0	3.5	6.5	11.5	4.5	104.0	3.9	6.4	1.6	4.8	72.0	2.1
	R_4	6.5	15.0	11.5	170.0	3.4	6.5	10.8	2.3	89.0	3.2	6.5	1.7	3.7	50.0	2.2
T_3	R_1	6.5	16.8	10.4	152.0	5.2	6.6	9.1	5.8	79.0	4.3	6.5	4.0	4.6	80.0	2.2
	R_2	6.5	20.1	12.4	149.0	4.2	6.6	9.7	7.2	73.0	4.1	6.5	3.5	4.9	69.0	2.4
	R_3	6.4	16.6	11.8	150.0	4.7	6.5	13.6	7.1	93.0	3.9	6.5	2.9	3.2	51.0	2.0
	R_4	6.5	21.0	10.9	153.0	4.9	6.5	11.6	6.6	93.0	4.2	6.4	3.2	3.8	55.0	2.2
T_4	R_1	6.3	12.8	12.1	150.0	4.5	6.5	10.6	4.4	71.0	4.8	6.2	4.0	2.5	50.0	1.5
	R_2	6.4	16.7	10.9	140.0	5.0	6.5	9.6	4.2	80.0	4.6	6.2	4.0	2.6	43.0	1.8
	R_3	6.4	18.3	10.0	157.0	3.7	6.4	10.5	4.2	82.0	4.5	6.2	4.0	3.3	43.0	1.7
	R_4	6.5	15.3	9.0	149.0	5.0	6.5	10.6	3.9	68.0	4.4	6.2	4.6	2.2	38.0	1.8

* All data, except pH, expressed as ppm.

Table 7

The effects of soil applications of TCA and fertilizer (10-10-10) on N, P, and K in plant tissue and on pH, NO_3, P and K contents of soil.

Treatments	Soil analysis p.p.m.				Plant analysis percent		
	pH	NO_3	P	K	N	P	K
C	6.3	2.8	0.6	4.2	2.75	0.492	2.00
CF	5.9	3.4	1.7	29.2	5.15	0.488	4.53
R_1	5.7	13.9	T	50.0	8.48	0.460	1.56
R_1F	5.5	19.5	1.2	50.5	9.55	0.593	1.86
R_2	5.7	15.3	B	26.5	9.03	0.528	0.90

Legend:

C	No treatment.
CF	Fertilizer only.
R_1	15 lbs TCA per acre.
R_1F	15 lbs TCA per acre and fertilizer.
R_2	30 lbs TCA per acre

Table 8

The effect of soil application of TCA* on amino acid, nitrogen and protein contents of wheat leaves (including stems).

	Non-treated		Treated		Non-treated		Treated	
	In the sample		In the sample		In crude protein		In crude protein	
Replications	1	2	1	2	1	2	1	2
	%	%	%	%	%	%	%	%
Nitrogen	5.39	5.37	6.67	6.65				
Protein (N 6.25)	33.69	33.56	41.69	41.56				
Methionine	0.35	0.36	0.39	0.40	1.03	1.07	0.94	0.96
Lysine	1.43	1.43	1.54	1.54	4.24	4.26	3.75	3.71
Valine	1.92	1.94	1.83	1.82	5.69	5.78	4.39	4.38
Leucine	1.77	1.77	1.83	1.89	5.25	5.27	4.39	4.55
Arginine	1.61	1.62	1.99	2.07	4.78	4.83	4.77	4.98
Histidine	0.70	0.73	0.78	0.80	2.08	2.18	1.87	1.92
Phenylalanine	1.21	1.24	1.35	1.33	3.59	3.69	3.24	3.20
Isoleucine	0.68	0.68	0.67	0.67	2.03	2.03	1.61	1.61
Threonine	1.27	1.29	1.27	1.27	3.77	3.84	3.05	3.06
Tryptophane	0.59	0.58	0.40	0.36	1.75	1.73	0.96	0.87

* 30 pounds TCA/A to Oshtemo sand.

Table 9

The effect of soil application of TCA* on amino acid, nitrogen and protein contents of wheat roots.

	Non-treated		Treated		Non-treated		Treated	
	In the sample		In the sample		In crude protein		In crude protein	
Replications	1	2	1	2	1	2	1	2
	%	%	%	%	%	%	%	%
Nitrogen	3.09	2.92	3.39	3.30				
Protein (N 6.25)	19.31	18.25	21.19	20.63				
Methionine	0.17	0.16	0.20	0.19	0.88	0.88	0.94	0.92
Lysine	0.67	0.61	0.72	0.66	3.50	3.34	3.40	3.20
Valine	0.94	0.93	1.03	1.01	4.87	5.10	4.86	4.90
Leucine	0.89	0.81	0.96	0.90	4.61	4.44	4.53	4.36
Arginine	0.85	0.76	1.06	0.94	4.40	4.16	5.00	4.56
Histidine	0.23	0.21	0.32	0.32	1.19	1.15	1.51	1.55
Phenylalanine	0.50	0.47	0.57	0.56	2.59	2.58	2.69	2.71
Isoleucine	0.30	0.34	0.36	0.33	1.55	1.86	1.70	1.60
Threonine	0.73	0.66	0.75	0.69	3.78	3.62	3.54	3.34
Tryptophane	0.17	0.16	0.20	0.19	0.88	0.88	0.94	0.92

* 30 pounds TCA/A to Oshtemo sand.

Table 10

The effect of soil application of TCA* on carbohydrates and ether extract contents of wheat leaves (including stems).

	Non-treated		Treated	
Replications	1	2	1	2
Reducing sugars%	2.90	2.93	3.20	2.58
Non-reducing %	8.20	8.49	2.74	2.92
Starch	0.65	0.72	1.04	1.26
Other polysaccharides	9.20	8.62	10.83	10.72
Ether extract %	5.37	5.37	2.33	2.47
Unsaponifiables**	1.02	1.05	0.51	0.54
Fatty acids**	1.57	1.27	0.84	0.83

* 30 pounds TCA/A to Oshtemo sand

** Chlorophyll free.

Table 11

The effect of soil application of TCA* on carbohydrate and ether extract contents of wheat roots.

	Non-treated		Treated	
Replications	1	2	1	2
Reducing sugars	3.82	3.83	6.63	7.86
Non-reducing	3.09	3.44	3.37	3.45
Starch	2.51	1.67	4.59	5.41
Other polysaccharides	20.95	21.05	16.89	16.24
Ether extract	2.86	3.02	2.18	2.33

* 30 pounds TCA/A to Oshtemo sand.

Table 12

The respiration rates of plant materials as affected by growth regulators and TCA treatments applied to soil and foliage.

Expt. no. 1	G. regulators 2	Concentration used 3	Plant materials used 4	Micro liter of O_2/hr. 5		
				Untreated	Treated	
1	TCA	30 lbs/A	Wheat foliage	229.7[1]	636.5[1]	
2	TCA	5,000 ppm	Cauliflower foliage	35.7[2]	50.0[2]	
			Tomato foliage	29.4	40.1	
3	TCA	5,000 ppm	Sugar beet foliage	20.3	30.7	
			Bean foliage	40.4	65.6	
				as affected by time		
				24 hrs	48 hrs	72 hrs
4	TCA	500 ppm	Wheat seeds	15.5[3]	47.1[3]	
	CMU	500 ppm	Wheat seeds	7.7	7.1	
	IPC	500 ppm	Wheat seeds	10.7	18.5	
	Endothal	500 ppm	Wheat seeds	5.7	5.7	
		Control	Wheat seeds	14.8	48.7	
5	TCA	5,000 ppm	Wheat seeds	7.9	23.3	6.7
		1,000 ppm	Wheat seeds	8.6	35.0	2.2
		500 ppm	Wheat seeds	14.4	31.3	4.4
		Control	Wheat seeds	9.1	49.4	3.9

1. per gram of foliage; 2. per sq. cm. of foliage; 3. per seed.

RATE OF GROWTH
MUCK SOIL (S_1).

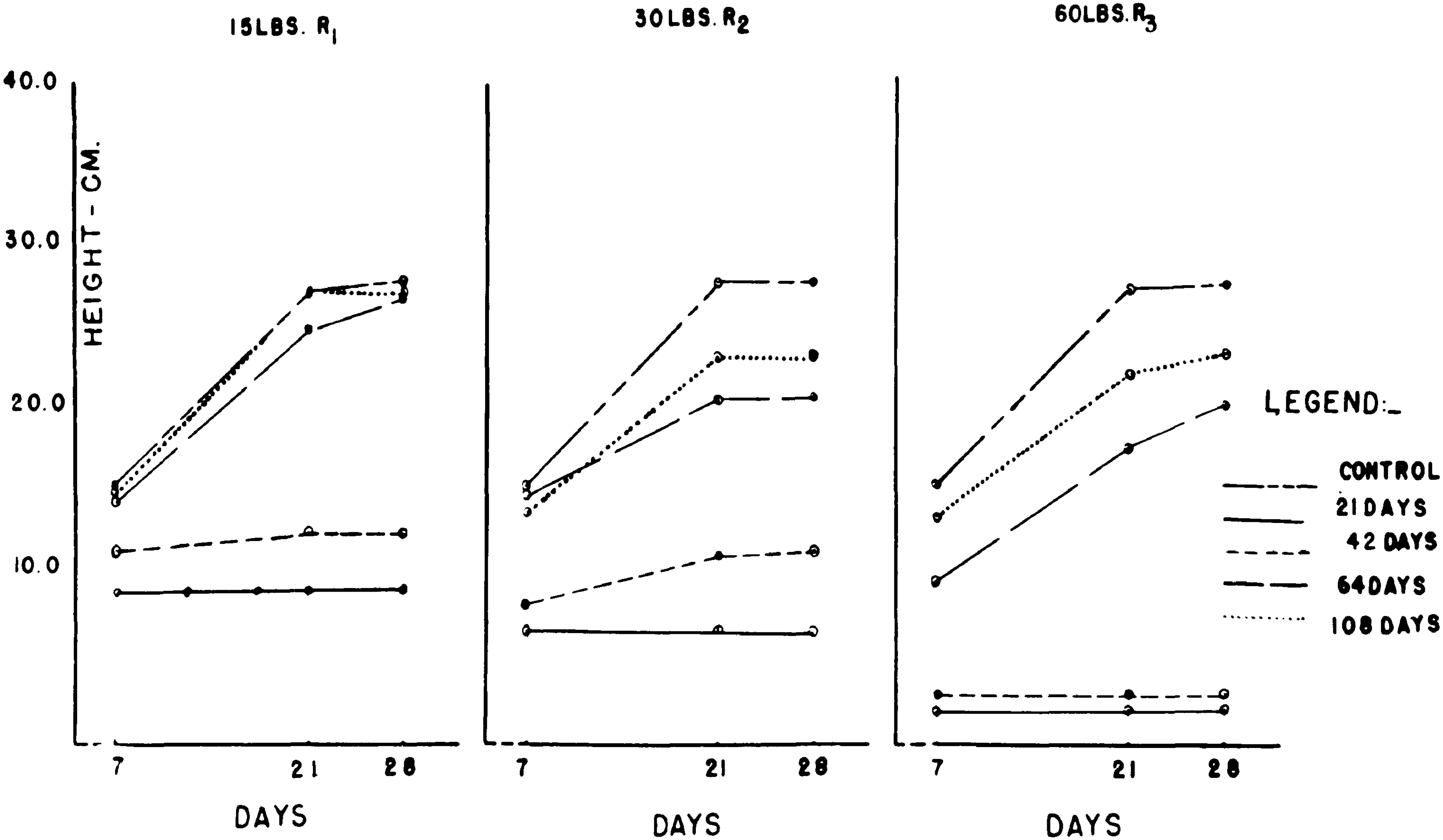


FIG. I. THE EFFECT OF RATE AND DATE OF APPLICATION OF TCA ON THE RATE OF GROWTH OF WHEAT ON MUCK SOIL

RATE OF GROWTH
CLAY LOAM (S_2).

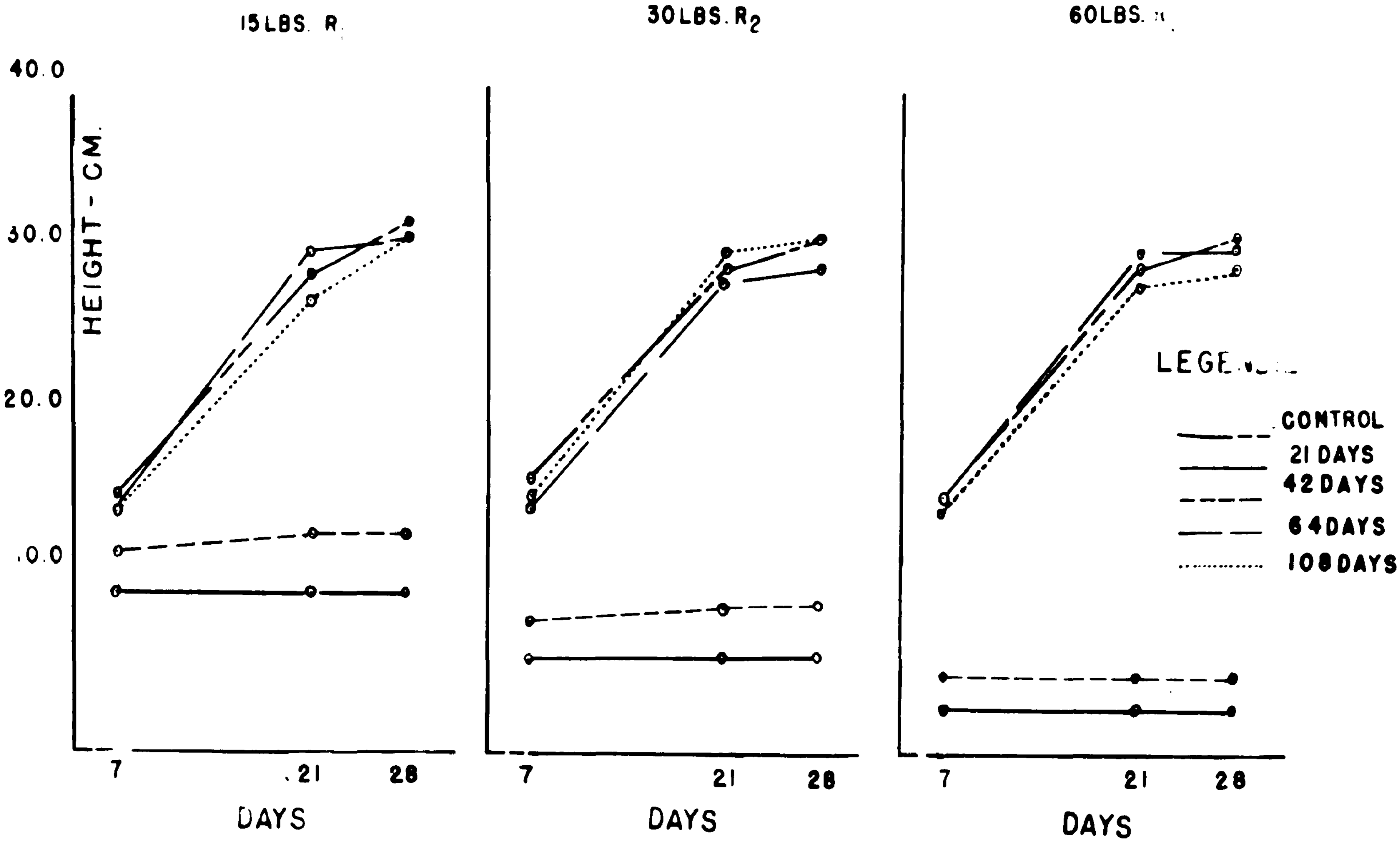


FIG.2. THE EFFECT OF RATE AND DATE OF APPLICATION OF TCA ON THE RATE OF GROWTH OF WHEAT ON CLAY LOAM SOIL

RATE OF GROWTH
SANDY SOIL (S_3).

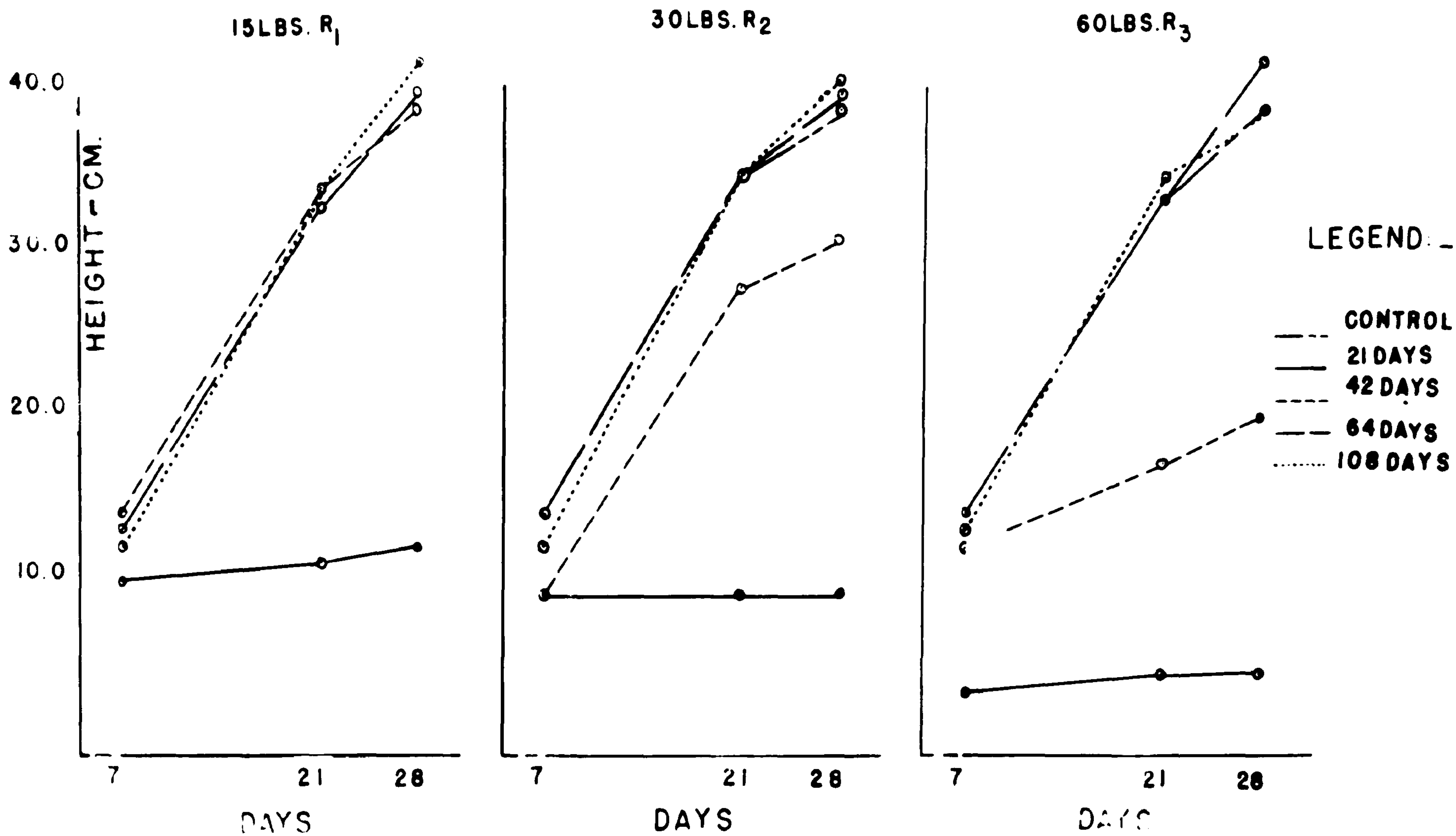


FIG.3. THE EFFECT OF RATE AND DATE OF APPLICATION OF TCA ON THE RATE OF GROWTH OF WHEAT ON SANDY SOIL

Legend:-

S - soil	R - rates	T - time elapsed between treatments and planting date
S_1 muck	R_1 15 lbs. TCA P.A.	T_1 21 days.
S_2 clay loam	R_2 30 lbs. TCA P.A.	T_2 42 days.
S_3 Oshtemo sand	R_3 60 lbs. TCA P.A.	T_3 64 days.
	R_4 Control	T_4 108 days.

Fig. 4. The effect of TCA on growth of wheat plants 20 days after planting.

Fig. 5. The effect of TCA on growth of wheat plants 30 days after planting.

DISCUSSION OF RESULTS

The results presented in the preceding pages show that under certain conditions TCA may seriously affect the growth of wheat plants. To explain the reason for the injury, wheat seeds were planted in Oshtemo sand immediately after application of 30 pounds of TCA per acre. The pictures, presented in Figures 6 to 10 inclusive, show that TCA did not affect the germination of the seeds. It was not until 10 days after planting that plants began to show the symptoms of injury. Apparently 30 pounds TCA per acre, mixed with soil, is not sufficient to affect wheat seeds. It is not until the plants have developed a root system that they take in sufficient chemical to cause injury. As the roots become more widespread the injury becomes more pronounced. Observations have shown that injurious effects from such salts as borax do not become evident in this manner.

It was thought that the injury was caused possibly by nutrient deficiencies since it developed slowly, as do starvation signs. The experiment with fertilizers was set up to obtain evidence on this possibility. The results, however, did not indicate nutrient starvation. The tips of the older leaves were first to turn yellow and later the whole leaf turned yellow. The process proceeded up the plant, leaf by leaf, until the plant died. Such affected plants had a retarded growth and sickly appearance as is shown in Figure 11.

In the experiments with the 3 soils such symptoms of injury appeared first on plants grown in soild which received treatments 21 days before the sowing of the seeds. The severity of injury was related to the amounts of TCA applied. These findings confirm the results obtained by other workers (34, 35, 41, 42). The nature of the soil had very little effect on the amount of injury which occurred during this time interval. The second time interval, 42 days in case of clay and Oshtemo sand, was almost long enough to prevent injury. This was especially true of Oshtemo sand where plant growth, in treated pots, was comparable to those of untreated pots.

Plants growing in treated muck were affected adversely even at low rates of TCA applications and for long intervals of time. The suppression of plant growth was directly related to the amount applied.

It seems safe to state, from the observations, yield data and growth curves presented, that the toxicity of TCA in soil depends upon the soil structure, moisture-holding capacity and organic content of the soils.

The particles of Oshtemo sand are of comparatively large size and hence expose little surface as compared to that exposed by an equal volume of muck or Brookston clay loam particles. Sand particles do not take part, to any great extent, in the physical and chemical activities of the soil. Relatively large spaces between the particles facilitate the movements of the air and drainage water. TCA, which is readily soluble in water (23), may have been leached from the upper layers of the sandy soil by gravitational movements of the water. The cultures were held at field capacity during the various time intervals. With longer time intervals, of course, more water was applied, hence there was more opportunity for leaching.

The moisture-holding capacity of the soil may explain, in part, the crop growth differences in three soil types used in the present studies. Experiments, conducted by Robbins et al. (57), with sodium chlorate showed that it's movement is much faster in sandy soil than in heavier soils. The results obtained in this investigation indicated that crop injury was the least in the sandy soil due to its low water-holding capacity.

Aeration, is beneficial to growing plants in an indirect way through the proper functioning of the microbial flora which elaborates the various materials of the soil into a form in which they can be absorbed and utilized by the plants. In a direct way, aeration of the soil benefits the plants by furnishing a supply of oxygen which is essential for the proper functioning of the protoplasm of the cells of the roots. Plant life processes were apparently being carried on normally in the control cultures. If aeration has any effect on the breakdown of TCA, then it might be logical to assume that it would breakdown faster in a sandy soil. Such was the case so it can be assumed that aeration did hasten the breakdown of the chemical. However, it is recognized that some fine sandy soils are as poorly aerated as many heavier soils.

Soil microorganisms are capable of bringing about biochemical processes in the soil whereby the organic compounds are decomposed to simple end products such as carbon dioxide, water and nitrates (51). The addition of a herbicide is likely to affect the activities of the microorganisms. Experiments performed in culture solution on the solid media have shown that high concentrations of 2,4-D, far above those which will cause injury to plant growth, are necessary to inhibit the growth of soil microorganisms (50). The measures of microbial activities such as carbon dioxide (50) or nitrate production (29, 63) or numbers of bacteria

(63) are not influenced by ordinary rates of soil applications of 2,4-D. However, this was not true with TCA applications to soil. Experiments (30) indicated that rates, as low as 10 pounds per acre, significantly reduced the microbial activity in the soil.

These statements prove the inhibitory effects of the herbicide on the activities of the microorganisms which might be a factor in the breakdown of the chemical.

In the muck and clay loam soils the long persistence of the herbicide may be explained on the basis of colloidal clay and organic matter content, the main constituents of such soils, and the fineness of the soil particles. The movement of the compound, in such soils, is restricted due to the smallness of the passageways between the soil particles and also by the colloidal adsorption of the chemical. Since the colloidal particles are charged bodies they may hold water molecules and dissolved herbicide molecules readily and firmly. The soil exhibits retention against leaching due to positive and negative charges which are carried by colloidal nuclei and water molecules respectively.

It is conceivable that colloidal particles may be linked by oriented water molecules (49). As the water evaporates, the mobility of the molecule is decreased, the herbicidal properties of the adsorbed particles are likely to become less pronounced. Under such conditions there is hardly any loss due to leaching and the persistence can be expected for a long period. Inactivation of the herbicide will result, in due course of time, because of the action of other mechanisms.

In arid regions, however, the applications of TCA must be accompanied by irrigation so that the salt can be brought into the root zone for effective weed control purposes. Under such conditions, crop planning schemes for the treated soils should take into consideration the knowledge of initial toxicity in various soils and changes in toxicity with time, and the effects of percolating water upon distribution of the chemical. Such studies, conducted with sodium chlorate, a water soluble compound, proved to be useful (57).

The data presented indicate that the availability of the soil nutrients was not affected by the applications of TCA to soils. The fact that crop growth, in treatments where the time of application was 64 days and 108 days before the sowing date of the crop, was comparable to plant growth of untreated cultures, shows that nutrient status of the soils was not changed by the treatments considered in this experiment.

The nutrient elements present in the soils are needed by the plant for building up plant tissues, protoplasm and enzymes. Such enzyme systems in plants, are built up out of proteins and nucleoproteins, and thus contain a large amount of nitrogen and phosphates with some sulphur (59). It is very likely that these enzyme bodies can not function properly or at least their effectiveness is greatly reduced in plants grown under toxic soil conditions.

The use of TCA in precipitation of proteins suggests that it may act as a precipitant of plant enzymes. Such precipitation, considered to be an irreversible reaction, brings about the death of the plants (1).

Furthermore, TCA absorbed by the roots is likely to upset the regulatory role of the nutrient ions in osmotic pressure and hydrogen ion concentration in the protoplasm, and thus may contribute to the causes of plant death.

Plant growth will take place only when there is adequate quantity of enzymes present along with adequate quantities of absorbed minerals (59). Experiments reported, herein, show that the intake of nitrogen, phosphorus and potassium was not affected in the case of injured plants. On the other hand the excessive quantities of total nitrogen in the plants growing in the treated soils indicate a lack of utilization on the part of the injured plants. Thus there was no growth, possibly due to lack of proper functioning of the enzymes.

From the respiration data presented it can be stated that TCA stimulated respiration in all the plant materials. This was found to be true by Rebstock *et al.* (56). They found further that the increased respiration did not occur during the first three days after treatment with TCA. This is in accord with the results presented in this paper in regard to the time when plants first showed symptoms of injury, fifteen days after the seeds were planted in TCA treated soil. Such stimulation of respiration can be considered as one of the causes of plant death.

In conclusion it seems likely that the death of the TCA treated plants was not the result of changes in the nutrient status of the soil but rather to a direct physiological effect upon the metabolism of the plants. This was further indicated by the results of Rebstock, Hamner, Lueke and Sell (56) who found that wheat plants treated with TCA did increase in nitrogen content and in content of arginine, reducing sugar and acid hydrolyzable polysaccharide. They found further that treated plants were decidedly lower in non-reducing sugars, ether extract, unsaponifiable material and fatty acids. Their work seems to verify the results obtained in this experiment, namely that changes in the plants affected by TCA were largely metabolic in nature.

The observations bring out a sufficient proof of the toxicity of high rates of TCA applications. If TCA is to be used for weed control on wheat lands then the application should be made at least 64 days in advance of the sowing date of the wheat crop. In case of muck soil it is safe to consider this toxic limit as 120 days or more. The toxicity of TCA diminishes progressively with the time.

From the experimental results it is apparent that the value of TCA lies in its inherent toxicity and its water solubility characteristic which helps in its dispersion throughout the soil zone occupied by roots. The dosage requirements of the compound will vary with weed species, soil type, rainfall, and other related factors. In order to be most effective, and distributed in a uniform concentration.

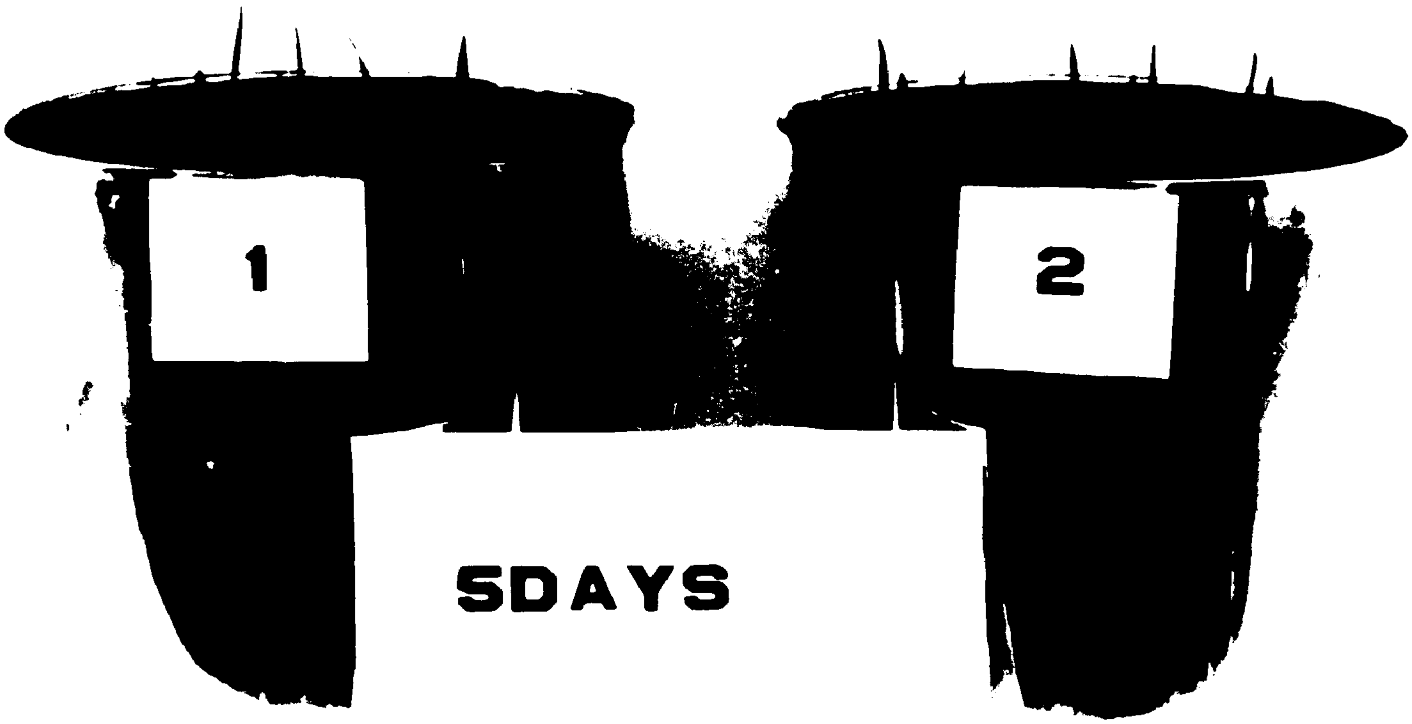


Fig. . The effect of TCA on germination and growth of ...

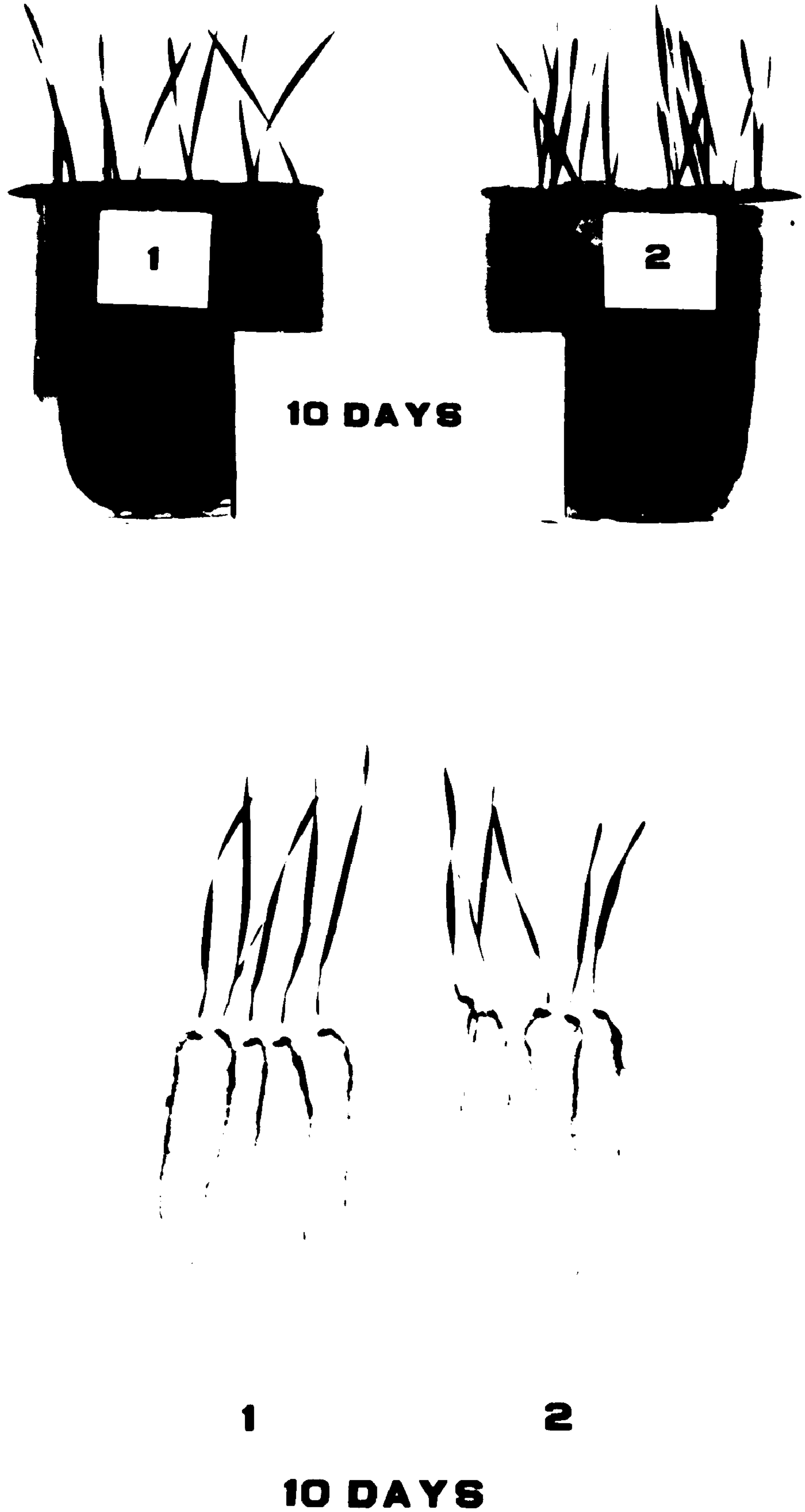


Fig. 7. The effect of TCA on growth of 10 day old wheat plants.

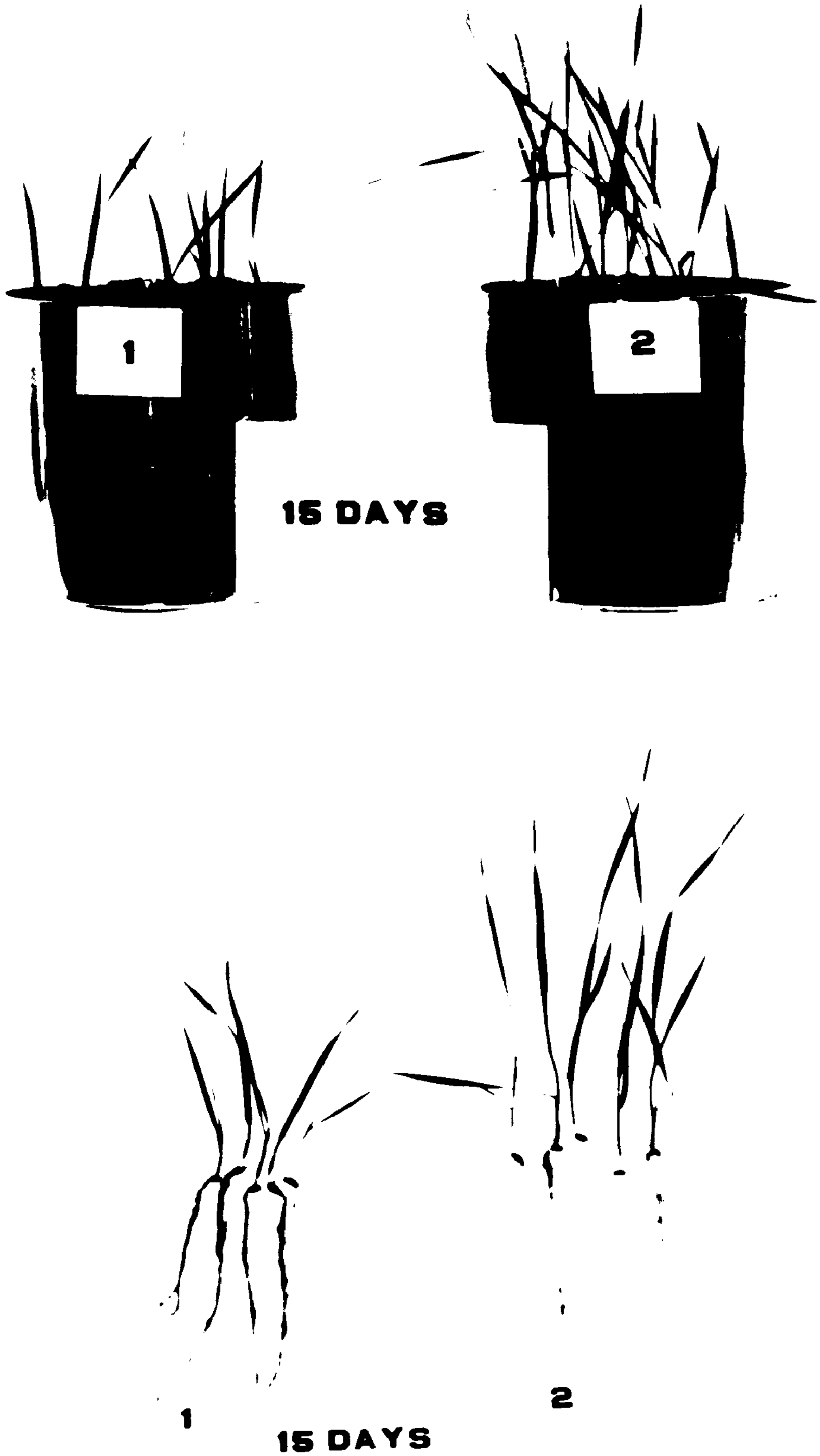


Fig. 3. The effect of TCA on growth of 15 day old wheat plants. Chemical applied on the day of planting.

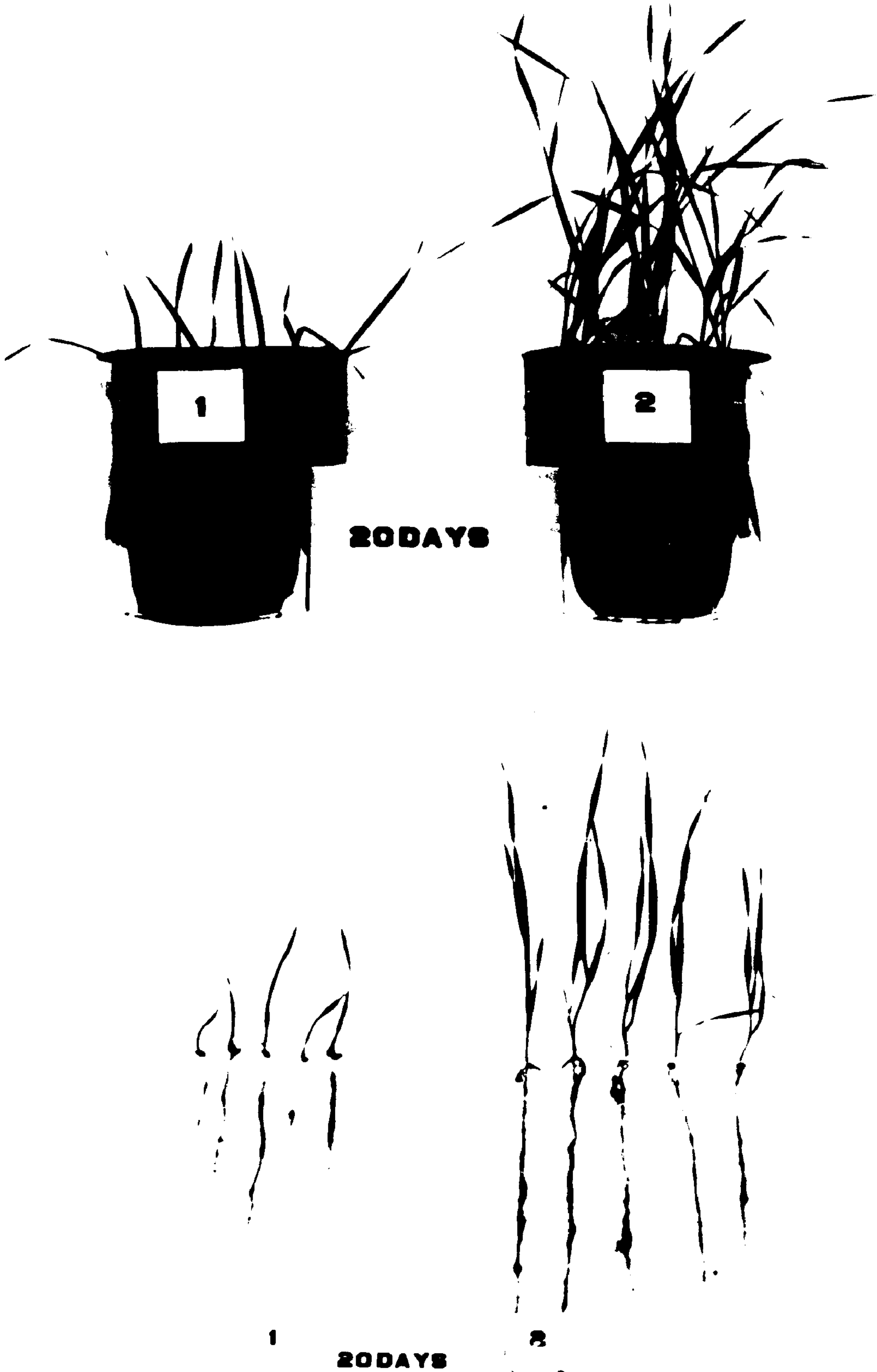


Fig. 4. The effect of TCA on growth of 20 day old wheat plants. Chemical applied on the day of planting.

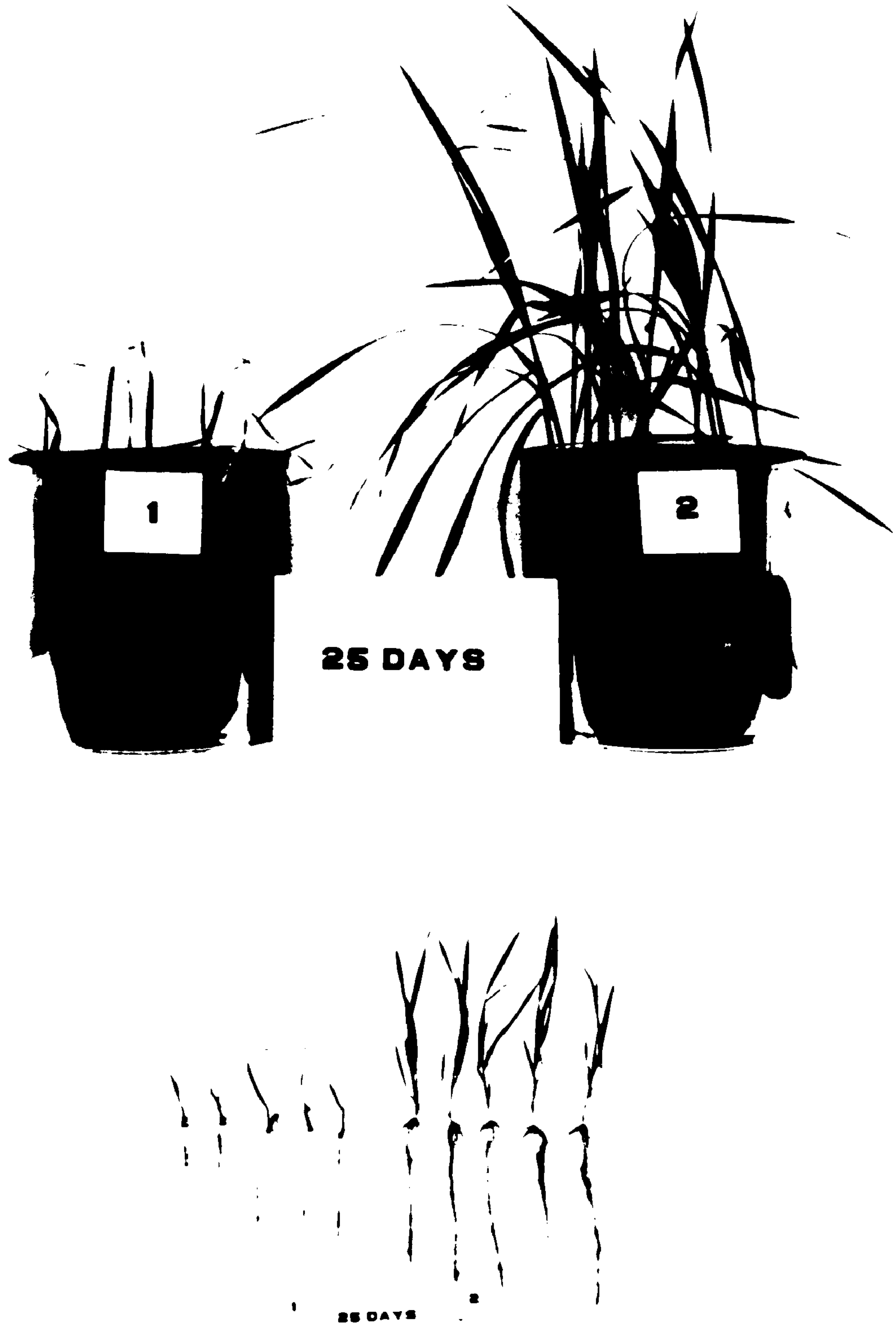


Fig. 1[illegible]. The effect of TCA on growth of 25 day old wheat plants.
Chemical applied on the day of planting.

Fig. 11. Wheat plants injured by TCA.

SUMMARY

The sodium salt of trichloroacetic acid was applied at three rates (15, 30 and 60 pounds per acre) to pots containing much, clay loam, and sandy soils. Treatments were made 21, 42, 64 and 108 days before wheat seeds were planted. Thus it was possible to determine the effect of soil type, rate of application, and time between application and planting on the growth rate and appearance of wheat seedlings.

The results of the study may be summarized as follows:

1. TCA proved very effective in suppressing the growth of wheat plants. This was borne out by fresh and dry weight of tops, dry weight of roots, and periodic rate of growth of plants.
2. The extent of injury was related to the rate of application of the compound, the 60-pound applications being the most injurious of all.
3. The greatest suppression of growth resulted, irrespective of the nature of the soil, when TCA was applied 21 days before the sowing date of the wheat seeds. Crop injury was in proportion to the amounts applied.
4. In the second period, where the application was made 42 days before the sowing time, there was little evidence of TCA injury to plants growing in sandy soil while those growing in muck soil were badly injured. The injury to plants grown on clay loam was intermediate. Growth behavior of the crop as measured by yield data was significantly different on each type of soil.
5. In clay loam and sandy soils the dissipation of TCA, as shown by wheat yields, was well under way by the time 42 days had elapsed

and was complete by the end of 64 days. However, this did not hold true with muck soil where injury occurred even after 108 days.

6. Soil nutritional levels, including pH, for available N, P, K, Ca, Mg, NH_4, and NO_2 were not affected by different treatments considered in this investigation.

7. The leaves of wheat plants treated with TCA contained a larger percentage of protein, arginine, reducing sugar and acid hydrolyzable polysaccharide. Slight difference was noted in other amino acids and starch. A tremendous decrease was observed in the percentage of non-reducing sugar, ether extract, unsaponifiable material. The crude protein showed approximately the same amount of methionine and arginine and slightly less of the other amino acids.

8. The roots of TCA treated plants showed a slight increase in the percentage of proteins and amino acids and also an increase in reducing sugar and starch. Little difference was noted in the other amino acids (expressed as percentage of crude protein), with the exception of histidine which was slightly greater in the treated plants, and in the percentage of non-reducing sugars and ether extract.

9. TCA injury to wheat plants was not the result of changes in the nutrient status of the soils but it was rather due to direct changes in the metabolic activities of the plants.

10. TCA treatments to plant tissues resulted in an increase of respiration rate.

11. Respiration studies with treated foliage of various plants indicated that sugar beet was most tolerant followed by tomato and cauliflower, while beans were least tolerant of all the plants studied.

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