A COMPARATIVE STUDY OF CHANGES IN THE SOIL CAUSED BY ADDITION OF MANURE AND CHEMICAL FERTILIZER

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PREFACE

This study is concerned with the analyses of soil before and after treatment with manure and chemical fertilizer to determine and compare changes that occur as a result of the additives. The primary objective is to determine whether or not the application of organic matter, such as waste from feedlots, causes beneficial changes in the soil of such magnitude that it becomes economically advantageous to dispose of waste from feedlots in soil systems rather than burning or conversion to fuel or building materials, as has been proposed. If such organic matter proves beneficial for agricultural purposes, then the concept could be extended to agricultural uses of other similar organic waste such as sewage and household garbage.

The author wishes to acknowledge his constant dependence on a very patient and helpful Lord who provided strength and stamina when human effort was inadequate to accomplish the task at hand. Next, sincere gratitude is expressed to Dr. D. F. Kincannon, primary faculty adviser, for his keen interest and support throughout this study. Appreciation is also expressed to Dr. James M. Davidson and Dr. Billy B. Tucker for technical advice in the field of agronomy, and to the Soils Lab personnel, who efficiently processed many and varied samples of soil.

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INTRODUCTION

The disposition of the solid waste extracted from the water by sewage treatment plants and that produced by beef cattle feedlots is presenting a challenge to water quality engineers. The very high degradability of these wastes makes it imperative that they be kept out of the surface water system lest they consume all of the available oxygen in the water. Of equal concern is the danger of nitrate pollution of water supplies as the waste is degraded and the nitrates are leached from the waste and carried with the water as it infiltrates and percolates to ground water supplies.

The preponderance of research being conducted now seems to be concerned with disposal means that treat the organic matter as a waste. Incineration and sanitary landfills are receiving the most attention because of the low capital investment and low operating cost. With the increasing scarcity of land for landfill operations, the possibility exists that incineration will be considered the primary means of disposal. Recent news releases indicate considerable success in using municipal refuse as fuel for steam and power generation, and using manure to produce low grade crude oil. However attractive these processes may seem, they may not be the most desirable overall because they are the result of looking for the cheapest disposal means of a waste rather than the most beneficial use of a resource.

However, if these organic by-products are considered a potential resource material, there are some rather intriguing solutions to the problems of disposition of these solids. Using this approach, an evaluation is made of the number of problems that can be solved simultaneously, considering the potential of the resource material. For this study, western Oklahoma was used as the area to be evaluated. Assuming the resource has agricultural potential, an assessment was made of the major agricultural problems in western Oklahoma. These problems were then compared with the alleged benefits of applying manure and sludge to the soil for biological stabilization. For the purpose of this research, these problem areas were narrowed to five, as follows:

1. The demand for beef in the United States has fostered a sharp increase in the number of large beef feedlots in western Oklahoma. Figure 1 shows the trend in Oklahoma in the number of cattle on feed. To keep the price of beef down to compete with other sources of beef and protein, U. S. cattlemen have resorted to consolidated feedlot operations. The problem arises out of the tremendous amount of manure produced per acre of land in use. Adding to the problem is the small margin of profit upon which the other ranchers in the area are operating which, they claim, will not permit them to pay even the handling cost of getting the manure on their land.

2. The second problem stems from the combination of population growth and the demand for cleaner water. The result is large amounts of sludge produced by the increasing number and efficiency of waste treatment plants. This sludge has characteristics similar to those of animal

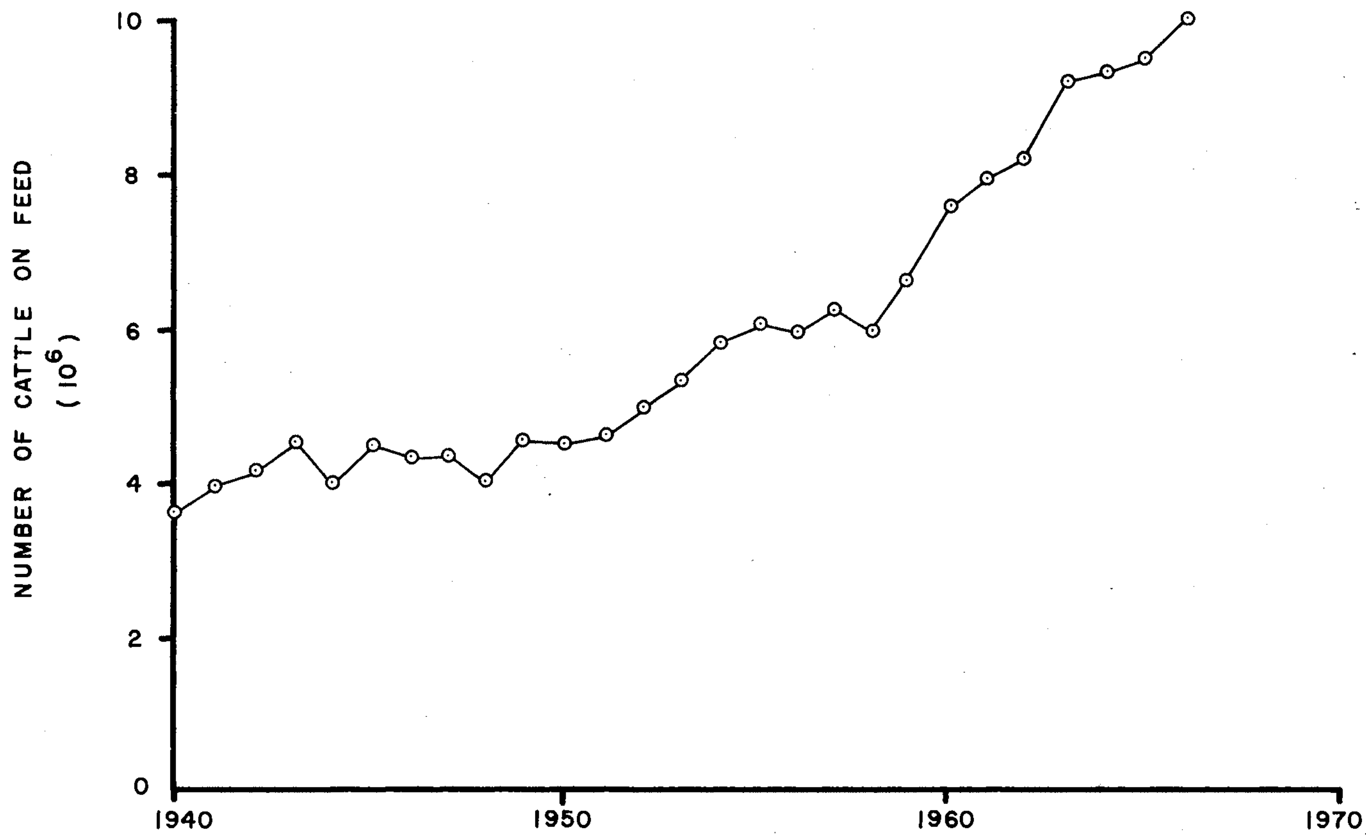


Figure 1. Number of Cattle on Feed
(Reference 19)

manure, and in many countries of the world it is used for fertilizer. However, in the United States there is an aversion to using the sludge for any agricultural purpose and especially on garden crops for human consumption. This aversion is in part because of the fear of passage of pathogenic organisms along with the food. However, many people just do not like the thought of eating vegetables grown on human waste. Therefore, as the price and scarcity of land for landfills increases, the disposition of this sludge becomes a problem.

3. The third problem identified in western Oklahoma is water shortage. This problem comes from the fact that the area receives 30 inches or less of rainfall each year, while the potential loss from evaporation is in excess of 60 inches per year. This means great amounts of water are lost from evaporation from irrigation operations and surface storage. Irrigation poses other problems also. The number of uses of water in the watersheds are causing buildups in the salt content (1). This concentration is further increased by evaporation until there is danger of ruining the soil by extending irrigation (2). Another factor is the price of irrigation water. Presently, water is undoubtedly the cheapest of all commodities, but the trend seems to be toward making those who use the water, clean it up before returning it to the resource pool. When this occurs, the farmer cannot afford to pay the price of water for most crops. Therefore, there is a need to store water where it falls, but NOT on the surface. It must be held underground, where evaporation losses are minimal.

4. The fourth problem identified is loss of organic matter from the soil. In the prairie soils of Oklahoma the organic content, or humus, has decreased during the past 70 years of cultivation from

approximately four percent to one percent or less in some cases. This trend is shown in Figure 2. If this trend is allowed to continue, the soil will resemble an inorganic conglomeration of elements so void of energy that it will not be able to hold itself in place, much less provide energy and nutrients for plant growth.

5. The fifth problem identified is the loss of top soil by erosion. It is not uncommon for as much as 200 tons of soil per acre per year to erode by a combination of wind and water. In the United States, four billion tons of soil erode each year from water alone. One billion tons of this is lost to the ocean; the remainder is deposited along the watershed as sediment. The greatest single factor in water quality management in Oklahoma is sediment.

The aim of this research was to evaluate the effects of applying manure to the soil, to determine whether or not it is profitable to dispose of organic by-products in the soil, and to evaluate the specific effect of the application of the organic matter as regards the water, humus, and topsoil loss in the area evaluated.

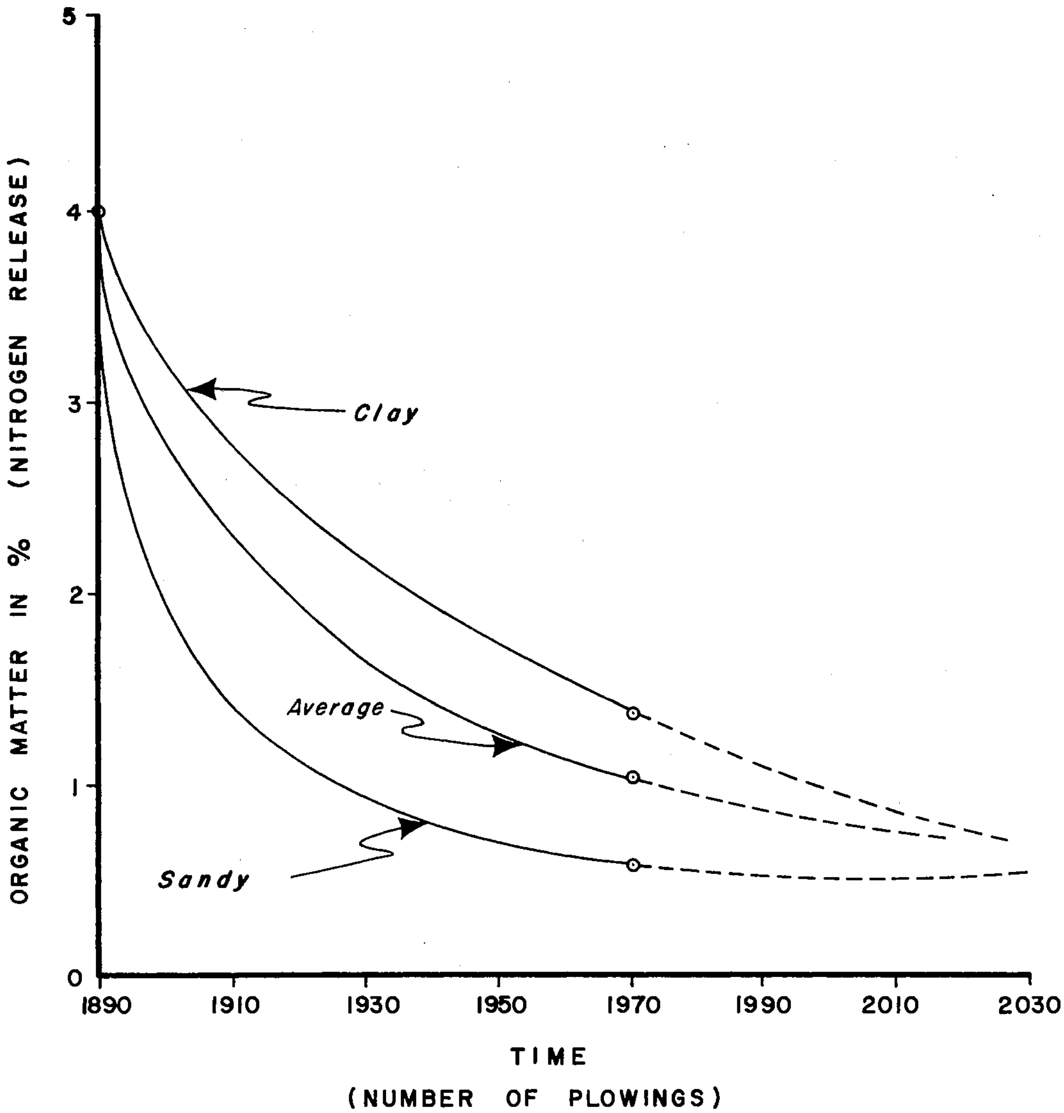


Figure 2. Decline of Organic Matter in Oklahoma Prairie Soil

CHAPTER II

LITERATURE REVIEW

A. Historical

Review of the data from research that has been conducted throughout the world is presented in two basic categories. First, the data pertaining to growth as a result of additives will be presented, followed by data pertaining specifically to changes in the physical properties of soil as a result of application of various substances. There is considerable variation in the data from the United States and Europe. Some can be explained, and some cannot. The result of research conducted in Europe, in general, is heavily in favor of the application of organic matter to the soil. The literature from Europe also lists far more specific data in regard to changes in soil as a result of addition of organic matter than does the literature from American research. European research compares chemical fertilizer with organic fertilizer which includes sludge, compost, and raw manure. There appears to be a resistance in the United States to the use of sludge as fertilizer. While many states do not have specific laws, there are rules set down by agencies, such as the Public Health Service, prohibiting the use of sludge on cropland which is going to be used to grow food for human consumption. These rules are primarily to prevent passing pathogenic organisms from human wastes back into the human system. In addition to this, there is a reluctance in the United States to the use of sludge from human wastes as fertilizer. It is difficult to pinpoint reasons for this. Once the waste has gone through a sewage treatment plant and has been digested in an aerobic or anaerbbic digester, it is no longer human waste but rather a large conglomeration of bacteria which has coagulated and settled. Therefore, the resistance cannot be justified scientifically since it has been confirmed that pathogenic organisms are killed at temperatures of 60^{o}C or higher (3). Since compost piles reach this temperature, if sludge were used in compost it would be free of viable pathogenic organisms. European literature also contains information regarding physical changes in the soil as a result of application of organics, whereas information of this type from work being done in the United States is very limited.

B. Chemical Analyses of Sludge Compost and Manure

Table I is a listing of chemical analysis of sewage sludge based on percentage of oven dry basis. This data was produced at the University of California. The chemical analysis of refuse compost and stable manure was produced in Europe and is on the percentage basis of the material without drying.

C. Composting in the Netherlands

Data pertaining to composting operations in the Netherlands, as reported by a compost working group in Amsterdam, makes specific reference to the fertility of the soil and breaks it down into chemical and physical fertility (4). Chemical fertility is that which pertains to the amount of nutritive substances present in the soil, the capacity of the soil to retain these substances, and the proportionate distribution

TABLE I

CHEMICAL ANALYSES OF SLUDGE, REFUSE COMPOST, AND STABLE MANURE

1a. Sewage Sludge*

	%	Micronutrients	ppm
Moisture	6.4	Iron	23,700
Ash	74.8	Zinc	1,460
Carbon	12.9	Manganese	520
Organic matter	22.2	Copper	95
Total N	1.07		
Protein N	.96		
Nitrate N	.07		
Total P	.34		
P sol. in 2% acetic	.17		
Total sulfur	.22		
Calcium	3.43		
Magnesium	.64		
Potassium	.74		
Sodium	.39		

Percentages, oven dry basis.
*Source: Vlamis, J., California Agriculture, July, 1971

1b. Refuse Compost, Stable Manure*

	Refuse Compost	Stable Manure
Moisture content (%)	41.0	77.5
Volatile solids (compustible matter)(%)	20.4	17.4
Humus carbon (inert carbon)(%)	5.8	5.2
Active organic matter (%)	14.7	12.3
Alkali-soluble humus (%)	4.8	5.0
Total nitrogen (%)	0.6	0.4
Phosphorous as P_2O_5 (%)	0.36	0.21
Potassium as K_2O (%)	0.43	0.43
Calcium as CaO (%)	5.3	0.9
Magnesium as MgO	0.65	0.23
pH value	7.6	7.3

The analyses are based on the fresh material (wet weight).
*Source: Hurter, H., IRGRD, Information Bulletin No. 4, March, 1958

between solid, liquid, and gaseous substances in the soil. Physical fertility is that which pertains to the size of the pores and the proportion of small pores which hold water compared to the large pores which hold air. Pore volume is largely dependent on soil structure--the ideal being designated as crumbly or friable.

The working group found that good stable structure depends on biological activity which can be treated and maintained only by regular application of organic fertilizer. Chemical fertility is cheaper to maintain by using chemical fertilizer, but physical fertility must be maintained and can be maintained only by organic fertilizer since there there are no organics added to the soil by the chemical fertilizer. Combining the chemical fertilizer with organic fertilizer has produced the greatest yield (4).

This compost working group reported the historical trend in Holland concerning fertilizer application. In the 1900s, insufficient manure was available, so chemical fertilizer was introduced to meet the demand for increase in yield. At that time the soil was fairly rich in humus, so there was a great increase in yield; therefore, the chemical fertilizer was hailed as being extremely effective, and compost and manure became a thing of the past because it was more difficult to produce and handle. Physical fertility was disregarded and began to decline until yield could not be increased by chemical fertilizer. It was then noted that many adverse things were happening. The first of these was susceptibility to short droughts. Also noted was an increase in susceptibility to disease. Third, an increased susceptibility to erosion by wind and rain was noted. It had taken nearly 50 years to realize the deficiencies existing in the soil, because of the gradual decline in the organic content of the soil.

D. Research in Germany

German agriculturalists have conducted extensive research on the effects of compost on the soil. First, they point out that an aerobic compost is best since the higher temperatures kill the pathogenic organisms. When compost is produced anaerobically, the temperature does not rise sufficiently. Dr. Farkasdi found that in aerobic composting piles, a temperature of 60^{0}C or greater was attained, and all pathogenic organisms were killed by the time the compost was mature (5). As a result of the research conducted in Europe dealing specifically with compost, it is concluded that compost should not be considered a true fertilizer, but should be classed as a soil builder (6). The primary advantages of compost are:

1. Improvement of soil texture, particularly of heavy soil, making these soils easier to till.
2. Increase in pore volume, which allows the soil to hold more water and more air.
3. The prevention of wind and water erosion.
4. The reduction of parasites and nematodes in the soil as a result of compost application.
5. The addition of trace elements and nutrients which can be used by the plants.

The research in Germany also affirmed the finding in Holland to the effect that it would take as long as 50 years to correct a deficient humus condition. Compost, therefore, is an organic fertilizer the main usefulness of which lies in its ability to maintain bacterial life in the soil. Bacterial life makes more active the influence of trace element, and bacteria play the role of buffers in relation to nitrogen, phosphorus, and other minerals. They found that because of long term improvement, where improvement may be slight the first year, or perhaps the second year, compost is being bought only when nothing else is available. The scientists in Germany believe that this is very wrong, and contribute the reason for this to the less spectacular results from the application of organic matter (6).

In one set of trials conducted in Germany during the period from 1949 to 1952, Steigerwald and Springer found that there was a 20-30 percent increase in yield from compost made from refuse only (7). They also found a 45 percent increase in yield from compost made from municipal refuse and digested sludge. They also found that humus increase was greater from compost made from digested sludge. Therefore, they are beginning to experiment with mixtures of compost made from two-thirds municipal refuse and one-third digested sludge.

In another set of experiments conducted at the Bavarian Institute for Plant Culture and Protection using fertilizer containing nitrogen, phosphorus, potassium, and refuse composted with sludge, these results were found (8): For the short term increase--that is, the first year--the chemical fertilizer was best with a 57 percent increase in yield, while compost alone had a 45 percent increase in yield. The second finding was that over a long term, the compost had a sustaining effect whereas the chemical fertilizer had no sustaining effect. The conclusion was drawn that compost should not be considered a fertilizer alone but a soil builder. The seven-year trial showed a significant improvement in the soil using two parts domestic refuse and one part dried sludge in the composting process.

Another set of data from research done in viniculture from Heilbroun, Germany, shows these results (9): First, soil fertility is a function of its humus content, the clay humus complex regulating all processes of the soil which act for the maintenance and enhancement of its biological activity. Specific results of their research were that the water content is regulated by rich humus content; second, humus enables the soil to hold more water and release it more slowly; tests with compost and stable manure showed a 40 percent increase in water-holding capacity. Third, they found that the absence of humus permits hard crusts to form which reduce absorption capacity and increases the risk of erosion. They also found that compost is better than stable manure for erosion control. Not only did they find that fertility of the soil was increased and physical properties of soil enhanced, but the quality of the grapes grown during the experiment was improved. Table II shows that the increase in quantity of the grapes during the final year of the tests was 30 percent, and a quantity plus quality increase of 34 percent.

In another trial they found that the increase was not as significant nor as sustained, but in a two-year rotation with fertilizer and compost they found that there was definitely an increase in the quantity and quality of yield during those years in which the compost was added (1953 and 1955). Another conclusion coming out of this research from Heilbroun was that compost is cheaper to haul than raw manure because it contains only 30 percent water, whereas raw manure contains 70 percent or more water.

TABLE II

VINICULTURE YIELD DATA*

	1952 (%)	1953 (%)	1954 (%)	1955 (%)	1956 (%)
Quantity	7	11	13	25	30
Quantity plus quality (Kg. of sugar)	4	20	18	24	34

(In comparable trials at the "Trollinger" vineyards, this steady increase in yield did not result but, in the year of compost application [2-year rotation with fertilizer], more or less greater increases in yield occurred):

	1952 (%)	1953 (%)	1954 (%)	1955 (%)
Quantity	3	16	4	11
Quantity plus quality (Kg. of sugar)	-	6	1	6

*Source: Klenk, E., IRGRD, Information Bulletin #2, April, 1957.

E. Reforestation Experiment in Düsseldorf, Germany

In this experiment, screened compost was applied to fallow soil of large, shifting sand dunes. The land was barren except for patches of scrub trees. The composting began in 1953, in amounts ranging from 0 to 30 tons per acre using refuse and refuse plus manure (10). The area was planted with timber trees such as fir, pine, spruce, and others. The growth as a result of the treatment is shown in Table III. Listed are only three values of application but, as can be seen, the increase of growth is very pronouced with the increase of application rate of compost.

TABLE III

TREE GROWTH AS A RESULT OF APPLYING COMPOST*

The height of pines on treated plots has been regularly observed since 1954, and is given below for three application rates:

Tons/hectare	Height of Pines (cm.) 1954	1955	1956
45 (18 T/A)	8.6	18.8	49.1
60 (24 T/A)	9.6	28.3	58.2
75 (30 T/A)	10.6	33.5	75.0

In the spring of 1957, measurements were taken before the beginning of spring growth by the overall height method. The tallest plants on a continuous flat surface plot of two meters were measured, 300 plants were measured on each plot:

	Height (cm.)		Diameter (mm.)	
Tons/hectare	Range	Average	Range	Average
45 (18 T/A)	25-74	43.7	6-20	11.1
60 (24 T/A)	30-88	57.1	7-20	12.5
75 (30 T/A)	41-97	70.5	7-23	14.9

Similar conclusions were reached with this method. All other 1954 trial plots showed results of growth that were in line with the above observations.

*Source: Cosack, J., IRGRD, Information Bulletin #3, October, 1957.

F. Effect of Compost on Root Growth

Other research conducted at Amsterdam on the effect of urban refuse on root growth showed some interesting results (11). Here, root growth in soil treated with compost at the rate of 30 tons per acre was compared to the root growth in soil treated with nitrogen, phosphorus, and potassium fertilizer. They used the root box shown in Figure 3 to make the comparison. The soil in one-half of the box was treated with compost; the soil in the other half was treated with chemical fertilizer.

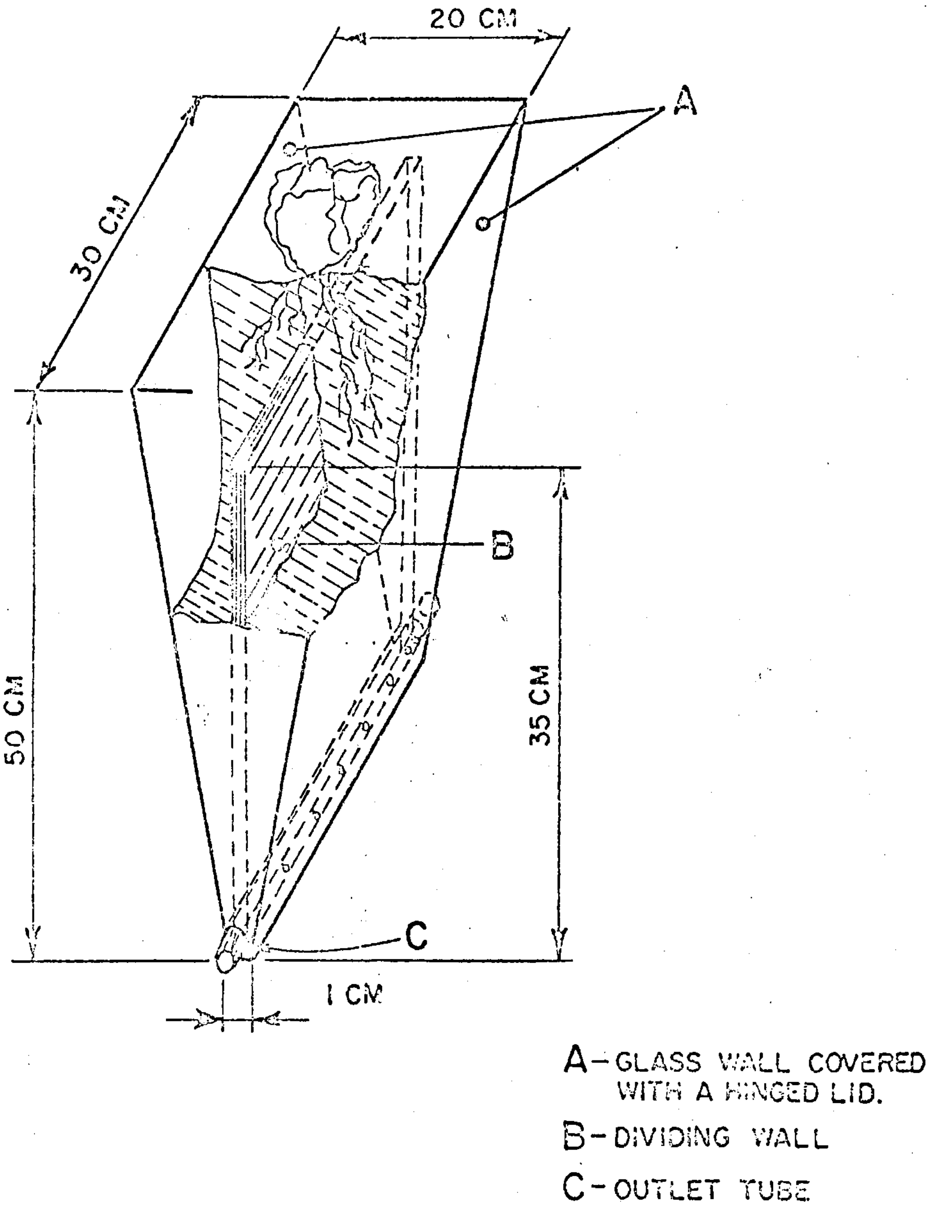


Figure 3. Rooting Box (Reference 11)

The plant was placed in the soil so that roots would grow down both sides of the box. The box was built so that pictures and measurements could be taken of the root growth, and the box was closed up in darkness so the roots could grow. In every case, using different plants, the root growth was substantially greater on the side using compost than it was on the side using chemical fertilizer. They found that the rate of nutrient absorption is proportional to total active root area. The ability to absorb nutrients is usually confined to the young parts of the root, usually having root hair. The volume of soil in contact with these parts is not more than one percent of total soil volume occupied by the root. Therefore, roots must keep growing to tap new nutrient sources.

The moisture content of the soil is one of the most important factors in root growth. Humus and other organic polymers can absorb more water and increase the available moisture reserve in the soil. They also influence soil structure favorably by minimizing water loss and preserving the oxygen supply to the root, thus reacting favorably on the root growth. Experience on almost all soil shows that those with the highest humus content have the most prolific growth. They also observed an increase in the assimilation of nitrogen, phosphorus, sulfur, and potassium absorption by root colloids. Thus, a part of this effect may be ascribed to an increased permeability of the root membrane caused by the humus. Again, the conclusion was drawn that humus and organic matter served more than a source of nutrients, and that perhaps the most important value of humus and organic matter is as a soil conditioner and stimulant (11).

G. <u>More Trials in Germany</u>

Considerable data ~~is~~ are available as a result of ten years of soil improvement tests conducted with peat, refuse, and sludge in Berlin, Germany (12). These trials began in 1920 with the lowland moors near Berlin being treated with Berlin compost at the rate of 132 tons per acre. After 40 years, these areas were evaluated. Soil samples showed exceedingly favorable results on physical and chemical fertility to depths of 40 cm. Table IV shows the result of sieve analyses made on this soil. As the table shows, the percentage of small particles was much greater in the area where refuse had been added. This means that the friability of the soil was considerably better. This effect went down to the 40 centimeter depth. It was also noted that the trace elements were increased an average of 700 percent in the soil as a result of refuse application. This is an area that has to be observed very carefully because an increase in some of the trace elements such as boron, copper, or zinc may have an adverse effect on the soil, and some plants will be sensitive to excess amounts of some of these trace elements.

After the soil was evaluated, the field trials were conducted on plowed wasteland, nutrient-poor, water-permeable, alluvial sand of weakly acid reaction that had been primarily pine woods. The soil was classified at the beginning of the test and at the end of the test. Four different situations were set up. On plot 1 there was no treatment; on plot 2 they used fresh peat; on plot 3 they used sieved refuse, and on plot 4, fresh sludge. All plots received a complete fertilizer (40-36-80). All plots (during 1950-51) received small amounts of fresh stable manure. The peat, sieved refuse, and the fresh sludge were

TABLE IV

SIEVE ANALYSES*

One kg. samples of fresh lowland moor soil from Hertefeld

Particle Size	Without Refuse %	With Refuse %
Surface:	Sample 4	Sample 7
Larger than 30 mm	13.3	6.4
15-30 mm	25.9	9.4
7-15 mm	40.0	17.7
3.7 mm	15.7	36.2
Smaller than 3 mm	5.0	30.2
At 40 cm. depth:		
Larger than 30 mm	21.7	2.3
15-30 mm	19.7	11.9
7-15 mm	36.1	22.5
3- 7 mm	12.4	34.7
Smaller than 3 mm	10.2	28.3
At depth greater than 40 cm.:		
Larger than 30 mm	78.4	79.8
15-30 mm	12.5	10.0
7-15 mm	6.6	6.7
3- 7 mm	1.4	2.6[1]
Smaller than 3 mm	0.8	1.3

[1]Ed. note: This value was shown as 22.6%, which was obviously in error.

*Source: Trinel, M., IRGRD, Information Bulletin #12, September, 1961.

added only once, at the beginning of the trial. Table V shows the result of the 10-year trial as pertains to growth from the various soil amendments. As can be seen, the overall growth from the decomposed refuse caused an overall increase of 26 percent. The peat showed an overall increase of 58 percent, primarily because of its longer-lasting effect. At the end of the 10-year period, there was evidence of only the peat remaining. During the period, it appeared that sludge had a longer lasting effect than the decomposed refuse. It was noted that in years of unfavorable weather conditions and generally low yields, the increase in yield due to addition of organic soil amendments was particularly high. This was especially so in light soils. The conclusion here is that the risk of yield is reduced by application of organic soil amendments.

The physical changes in the soil occurring as a result of the various soil amendments are shown in Table VI. Note that the organic content of the soil as a result of peat is the only one that increased significantly over the 10-year period. That which had only refuse, maintained the organic content, and that which had sludge, increased one percent over what it was at the beginning. Also note that the water percentage in the soil where peat had been added was almost doubled, and there was some increase in the other cases with refuse and sludge. The summary of the findings of this 10-year field trial is shown below:

1. Soil physical properties (humus content, hygroscopic moisture, water retention capacity, absorption capacity) were particularly improved by the peat. Chemical properties, on the other hand, were improved over long periods, particularly by the refuse and sludge.

TABLE V

YIELDS IN SOIL IMPROVEMENT EXPERIMENTS IN REHBRUCKE*
1947-1956

Soil Amendment	1948 Winter Rye			1949 Winter Rye			1949 Summer Rye			1949 Oats			1950 Winter Rye		
	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %
None	16	3.2	100	128	25.6	100	33.1	6.6	100	24.1	4.8	100	40.0	8.0	100
Fresh peat	-	-	-	161.1	32.2	126	78.3	15.7	263	34.6	6.9	144	88.0	17.6	220
Mature refuse	156	31.2	975	116.0	23.2	91	37.7	7.5	114	66.3	3.3	275	75.0	15.0	188
Sludge	-	-	-	164.2	32.8	128	63.3	12.7	191	42.2	8.4	175	60.0	12.0	150

Soil Amendment	1951 Winter Rye			1952 Lupine			1953 Winter Rye			1955 Serradella			1956 Winter Rye		
	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %	Kg.	Cwt ha	Rel. %
None	115	23.0	100	35.0	7.0	100	75.5	15.1	100	42.5	8.5	100	126.0	25.2	100
Fresh peat	168	33.6	146	33.0	6.6	94	72.5	14.5	96	48.5	9.7	114	134.5	26.9	111
Mature refuse	115	23.0	100	34.0	6.8	97	87.5	17.5	116	30.5	6.1	72	113.0	22.6	90
Sludge	165	33.0	143	30.0	6.0	86	83.5	16.7	111	30.0	6.0	71	127.5	25.5	101

1947 - No results because of unusual drought.
1954 - Plots were flooded for much of the summer and most test plantings rotted

*Source: Trinel, M., IRGRD, Information Bulletin #12, September, 1961.

TABLE VI

SOIL ANALYSES AFTER LONG TERM GROWING TESTS*

Constituent	Plot				
	Adjacent to Test Field	1	2	3	4
	Unfertilized	Complete Fertilizer (N, P, K, Ca)			
	Untreated	Without Amendment	Peat	Refuse	Sludge
pH in n-KCl Suspension	3.7	5.7	6.0	7.2	6.1
Organic Matter, %C (after Kurmies)	0.64	0.8	1.4	0.8	1.0
Hygroscopic Water, % (after Mitscherlich)	0.56	0.8	1.71	0.89	0.99
Max. Absorption T-value in meg/100g	-	3.0	6.2	3.7	3.3
Basic Deficiency T-S in meg/100 g	-	1.4	1.6	0.0	1.1
Lime Needed cwt/ha CaO	32.0	12.0	14.0	0.0	9.0
P_2O_5 in mg/100 g	9.5	13.6	11.4	22.1	18.6
K_2O in mg/100 g	1.1	7.2	3.9	13.7	7.6

*Source: Trinel, M., IRGRD, Information Bulletin #12, September, 1961.

2. Peat, mature refuse, and sludge applied to poor soil appreciably increased the yields of winter and summer rye, oats, and potatoes, and improved the certainty of yield in dry years for prolonged periods (about four to five years).

3. These results, however, were obtained by the application of large amounts of organic material. As a result of high haul and distribution costs of the soil amendments, refuse compost and sludge may be considered mostly for special crops, such as gardening and viniculture. The high boron and copper contents of refuse must always be kept in mind for boron-sensitive plants to avoid reductions in yield.

4. The known unfavorable action of the amendments used on lupine and serradella cannot be explained, but may be traced to the high boron content.

5. These experiments confirmed the well-known fact that organic matter is rapidly decomposed in light soils.

The enhancement of the soil's physical properties was the most significant aspect of this research. Also (in paragraph 2 above) it is specifically pointed out that amendments were applied to poor soil. This may be one of the reasons for the great difference in data found in research conducted with the application of organic amendments to the soil. If the soil is high in organic matter at the beginning of the test, the chances are that growth factors and the chemical and physical changes will be minimal. However, if the organic content of the soil is low at the beginning of the test, one might expect to find significant changes in the yield data and in the chemical and physical properties of the soil. Therefore, research conducted in the application of organic amendments should be started with soil known to have a deficiency in organic content. Note that this had been the big argument given in many cases for calling organic matter a soil conditioner rather than a fertilizer. And after all, this is why substances are applied to the soil--to correct a deficiency that exists. If a deficiency in humus exists, it cannot be corrected with chemical fertilizer.

Herr Andres, the agricultural engineer from Bad Kreuznach (6) is quoted:

> "A principal concern today of agriculture is the maintenance of a good condition of soil, which, despite abundant applications of nutrients, is losing its fertility to an increasing extent, becoming sterile, and becoming more and more difficult to till."

He also states that:

> "Many of the symptoms of soil regression are: loss of crumbly state, destruction of structure with resultant packing and loss of water-holding capacity, increasing stagnation and deficient aeration, reduction in yield [he states that his experience has been that up to 22 percent loss in yield can be traced to the lack of humus in the soil], crops become more susceptible to disease, and increase in erosion."

He also states that the regression is traced to one source: <u>the loss of humus content in the soil.</u> This loss of humus content can be replaced only by some type of amendment which has a high content of organic matter. In Germany, they have found that compost is the best at replacing the humus content in the soil because crop waste is inadequate, animal waste is decreasing, and green manuring is not possible for many crops growing in Europe. He states further that:

> "The problem has stemmed primarily from preoccupation by agriculture with chemical problems and genetics to the neglect of physical and biological aspects of the soil. Compost and manure have their primary importance in the area of soil improvements and not as a nutrient source. Soil improvement is a very complex and lengthy process. Because compost and manure may not show a sharp increase in yield, comparison between yield data can only result in false interpretations and erroneous conclusions.

> However, this has been done, and as a result, compost and manure are reported to have very little value in modern scientific farming. The result has been a gradual decline in the humic value of our soil. Research has positively proven that increasing the humus content of the soil increases the soil fertility."

These conditions especially have been noted: the physical, biological, and chemical effects are balanced when the proper humus content is present in the soil; organic matter also adds primary nutrients; it also adds trace elements. When organic matter is added, the friability of the soil is increased, and parasites and plant disease reduced. It is well to make an observation here: the conditions are varied, and every farmer may have a different condition of soil and different needs to be met. Therefore, it seems that every farmer should want to tailor his own improvement program.

H. Effects of Urban Refuse Compost

Research done in The Netherlands on the long term effects of urban refuse compost resulted in the following conclusions (13):

1. The short term effect is a supply of nutrients from decomposition of unstable organic and inorganic matter soon after the compost is applied.

2. The long term effects are based on the increase in the humus content of the soil. Humus content changes very slowly. It takes a long time to decrease it, and it takes a long time to increase it once it has been reduced. The humus content of the various soils in The Netherlands has been found to vary from two to seventeen percent. They found that the optimum for potato growth was seven or eight percent. The average content of Dutch soil is about four percent. As an example of the restructuring of the humus content of the soil, suppose a plot

of ten acres of soil has four percent humus and a topsoil weight of 8,800 tons. After an application of 8.8 tons per acre per year of stable manure over a 10-year period, also plowing in 1.3 tons of plant residue per acre per year, the result at the end of the 10-year period would be an increase of only 0.35 percent, or a total humus content of 4.35 percent. At this rate of application, it would take 150 years to build the humus content of this soil to 5.9 percent.

3. The trials also indicated that a principal function of humus is moisture content regulation. In this regard, and considering the length of time that it takes to rebuild a humus content of a soil after it has been depleted, one of the agricultural engineers from the Institute for Soil Fertility in The Netherlands, stated:

> "It is criminal to burn refuse instead of returning it to agriculture where all sources of organic manures are insufficient to maintain the optimum humus value in the soil. This should be given due consideration in deciding the practicability of methods of refuse disposal."

I. <u>Results from Japan</u>

An experiment was conducted in Japan for growing vegetables on soil treated with refuse compost (14). The soil was treated at the rate of three tons per acre and six tons per acre. The result of this experimentation on the humus content of the soil is shown in Table VII. It is noted that the only application which increased the humus content was with six tons per acre of compost which produced a humus content of 3.06 percent, as opposed to 3.03 percent at the beginning of the expermentation.

This series of experimentations conducted in Japan yielded the following results:

TABLE VII

pH VALUE AND HUMUS CONTENT OF SOIL IN THE CELERY EXPERIMENT*

	pH	Humus Content %
Start of experiment	7.1	3.03
After experiment, without compost	4.9	2.17
After experiment, 3 T/A compost	5.8	2.55
After experiment, 6 T/A compost	6.7	3.06
After experiment, 3 T/A stable manure	5.2	2.20
After experiment, 6 T/A stable manure	6.2	2.72

*Source, Nakamura, N., IRGRD, Information Bulletin #17, May, 1963

1. The refuse compost proved to be equal or superior to stable manure.

2. The addition of three tons per acre gave a higher yield than that of six tons per acre of compost. The optimum amount is probably about four tons per acre.

3. The compost not only increased the yield in sugar content of sugar beets, but also reduced the content of nitrogen. This reduction is favorable for sugar processing.

4. In an onion experiment, it was found that a concentrated application of compost directly in the rows resulted easily in an overdose.

5. During the celery experiment, it was noted that the pH value

of the soil is not increased but the acid effect of the necessarily high salt additions is neutralized. Maintenance of humus in possible only with compost and an amount of six tons per acre is sufficient.

J. Yield Data From the United States

Research conducted in the United States evaluating the utilization of farm animal waste has shown the following positive effects on the soil:

1. Improves soil tilth
2. Increases water-holding capacity
3. Lessens wind and water erosion
4. Improves aeration in the soil
5. Promotes growth of beneficial soil organisms.

It is interesting to note that these five conclusions listed above are synonymous with the conclusions from the European experimentations. However, quantification of these improvements have been difficult to find. This particular data is from the results of a Ph.D. thesis conducted at the University of Wisconsin in 1970 (20). The yield data from this experimentation is shown in Table VIII. Note that the growth from steer manure is considerably greater than that from dairy cow manure. Also, it is interesting to note that the greatest yield was a result of applying anaerobic liquid. This is liquid that has been stored under anaerobic conditions until application time. The next best was from fermented manure. Fermented manure is manure which is kept in large piles until application time. This is the same thing farmers used to do when they piled it behind their barns during the winter months and applied it in the spring.

TABLE VIII

EFFECT OF METHOD OF HANDLING OF DAIRY COW AND STEER MANURES ON AVERAGE YIELD AND RECOVERY OF N, P, AND K BY ONE CROP OF CORN GROWN ON A MIAMI SILT LOAM IN POTS*

Type of Manure[a]	Yield[b]	Yield Increase	Recovery by Crop[b] N	P	K
	g/pot	%	%	%	%
No manure	11.0		-	-	-
Dairy cow					
Fresh	19.5	77	44.0	19.5	40.5
Fermented	19.5	77	42.0	22.5	49.5
Aerobic liquid	17.0	55	18.5	19.5	38.0
Anaerobic liquid	22.5	100	52.5	29.0	48.0
Steer					
Fresh	32.0	190	53.0	23.5	73.5
Fermented	32.5	190	54.5	23.5	74.0
Aerobic liquid	20.5	86	13.0	14.5	34.5
Anaerobic liquid	33.0	200	65.5	27.5	83.0

[a]Manure applied at rate of 15 tons/acre on fresh-weight basis including two percent oat straw. Tons/acre - tons/2,000,000 lb. of acre furrow slice.

[b]Average of three replications and drying treatments; recovery values calculated on fresh-weight basis for manure.

*Source: "R. F. Hensler, Cattle Manure: I. Effect on Crops and Soils; II. Retention Properties for Cu, Mn, and An." Ph.D. thesis, University of Wisconsin, Madison, 1970.

Table IX shows the effects of different methods of handling dairy cow manure on the growth rate of grain and stover. Again, it is noted that a significant increase occurred in each case over a plot which had no manure applied; the greatest increase occurred when fermented manure was applied in the spring. This confirms that the old farmer was a scientific farmer.

TABLE IX

EFFECT OF TREATMENT OF DAIRY-COW MANURE AND TIME OF APPLICATION TO ROZETTA SILT LOAM ON A 3-YEAR AVERAGE YIELD AND RECOVERY OF N, P, AND K BY CORN AND ON RUNOFF AND NUTRIENT LOSSES*

Type of Manure[a]	Time of Application	Grain	Stover	Yield Increase	Rec. by Crop[e] N	P	K
		bu/a	tons/a	%	%	%	%
No manure	-	63	2.0	-	0	0	0
Fresh	Winter[d]	84	2.3	33	20	5.4	27
Fermented	Spring	97	2.6	54	44	10.7	46
Anaerobic liquid	Spring	91	2.3	44	45	11.7	30

[a]Manure applied at rate of 15 tons/acre on fresh-weight basis.

[b]Three-year average from duplicate plots; treatments followed by the same letter are not significantly different at the 10% level of probability.

[c]Recovery based on analysis of nutrients in fresh manure.

[d]Manure applied on frozen ground in winter and incorporated in spring before planting at the same time as manure applied in spring.

*Source: R. F. Hensler, "Cattle Manure: I. Effect on Crops and Soils. II. Retention Properties for Cu, Mn, and An." Ph.D. thesis, University of Wisconsin, Madison, 1970.

A result of the experimentation conducted at the University of Wisconsin was that in the case of alfalfa hay there was little or no increase in yield as a result of application of manure. This indicates one of two things: either some crops are not particularly benefited by manure application, or the humus content of the soil was sufficiently high at the beginning of the experiment for that particular crop to grow. This is confirmed by some of the data coming out of Europe. Legume crops in particular were not affected significantly by the addition of compost or manure.

One of the things that has been a deterrent to using organic waste is the cost of transportation. Michigan State University conducted some tests to see if they could dry chicken manure to make it easier to handle (20). The results of their experiments are that they could dry the manure for $16.60 per ton, and that it could be sold for about $20 per ton. This is not much profit, but at least the process pays for itself, which may be what we will have to settle for in waste disposal.

There are two obvious needs: first, research is required to find cheaper ways to produce composted organic fertilizer; second, society must be willing to pay the price, if necessary, for producing the high quality food they desire to eat.

K. Utilization of Municipal Organic Waste as Agricultural Fertilizer

The University of California at Berkeley conducted a test using sludge mixed with chemical fertilizer to compare the value of municipal sludge in agricultural uses (2). In these tests, Red Bluff loam was used and was fertilized only with sludge. The soil at the beginning of the test was found to be very deficient in nitrogen, phosphorus, and sulphur. The rate of application of the sludge was 0, 10, 20, 40, and 80 tons per acre. To compare the effects of the sludge with various kinds of fertilizer, there was a check plot run. There was fertilizer added: one with NPKS, one with PKS, one with NKS, and one with NP. In the case of the chemical fertilizer addition, there were severe deficiencies when either nitrogen or phosphorus was not added, and plant growth was severely stunted. This would indicate first of all that all of the elements for a balanced diet were provided with the sludge, whereas, when using only the chemical fertilizer, the omission of any one of the nutrients may severely hamper plant growth. Tests were also run with mixes of sludge, compost, and fertilizer. The results of these tests will be summarized only.

1. It was concluded that sludge can be disposed of in low fertility soil with no adverse effects at rates as high as 80 tons per acre, and when composted, up to 60 tons per acre. It is possible it could be higher, but higher rates were not compared during this test. At the 80-ton rate of sludge, some yield depression was obtained when chemical NP or NPKS fertilizer was included.

2. The organic wastes were found to be good sources of nutrients and increased the yield of tomato, barley, and lettuce crops by substantial amounts.

3. The maximum yields were obtained when the materials were used with the proper rate and combination of chemical fertilizers.

4. The wide variations of the physical and chemical properties of the organic wastes make it necessary that each waste be evaluated prior to application.

5. The agricultural utilization of sewage and garbage compost may provide a useful outlet for the disposal of municipal waste products.

L. <u>Physical Fertility From Experimentation in Europe</u>

The first series of experiments summarized are those dealing with the influence on the physical fertility of soil application of compost conducted at Bad Kreuznach, Germany (21).

Plant yield depends upon the use of proper amounts and balance of nutrients, but these cannot produce plant growth unless other growth factors, such as water, are present. In the Bad Kreuznach area they receive 400-450 millimeters (15-17 inches) of rainfall per year. This rate of rainfall compares with the arid southwestern United States. Therefore, the area is exceptionally dry and the most critical growth factor is water. The area may be dry for four months, then have torrential rain which causes severe erosion on steep, bare slopes which are used for growing grapes. For several years, the farmers of Bad Kreuznach applied only organic fertilizer to the vineyards, but as availability of animal waste decreased and commercial fertilizer became available, methods of fertilization shifted. Before long, erosion began to occur and yields began to be inferior in both quality and quantity. This became so severe in places that it was concluded that it is impossible to operate vineyards successfully without application of organic matter to keep the soil healthy and active.

After realizing the origin of the problem, the people of Bad Kreuznach opened a compost plant to increase availability of organic matter. In 1959, tests began to quantify the effects of organic fertilizer in the soil. These studies were aimed primarily at the physical properties of the soil.

The first significant finding was during the summer of 1960, an exceptionally dry year. Samples of soil taken between the rows of vines yielded considerably higher moisture content on the plot which had been treated with compost than those which were not treated with compost. These results are shown in Figure 4. Note especially the significant increase in moisture content from July to November.

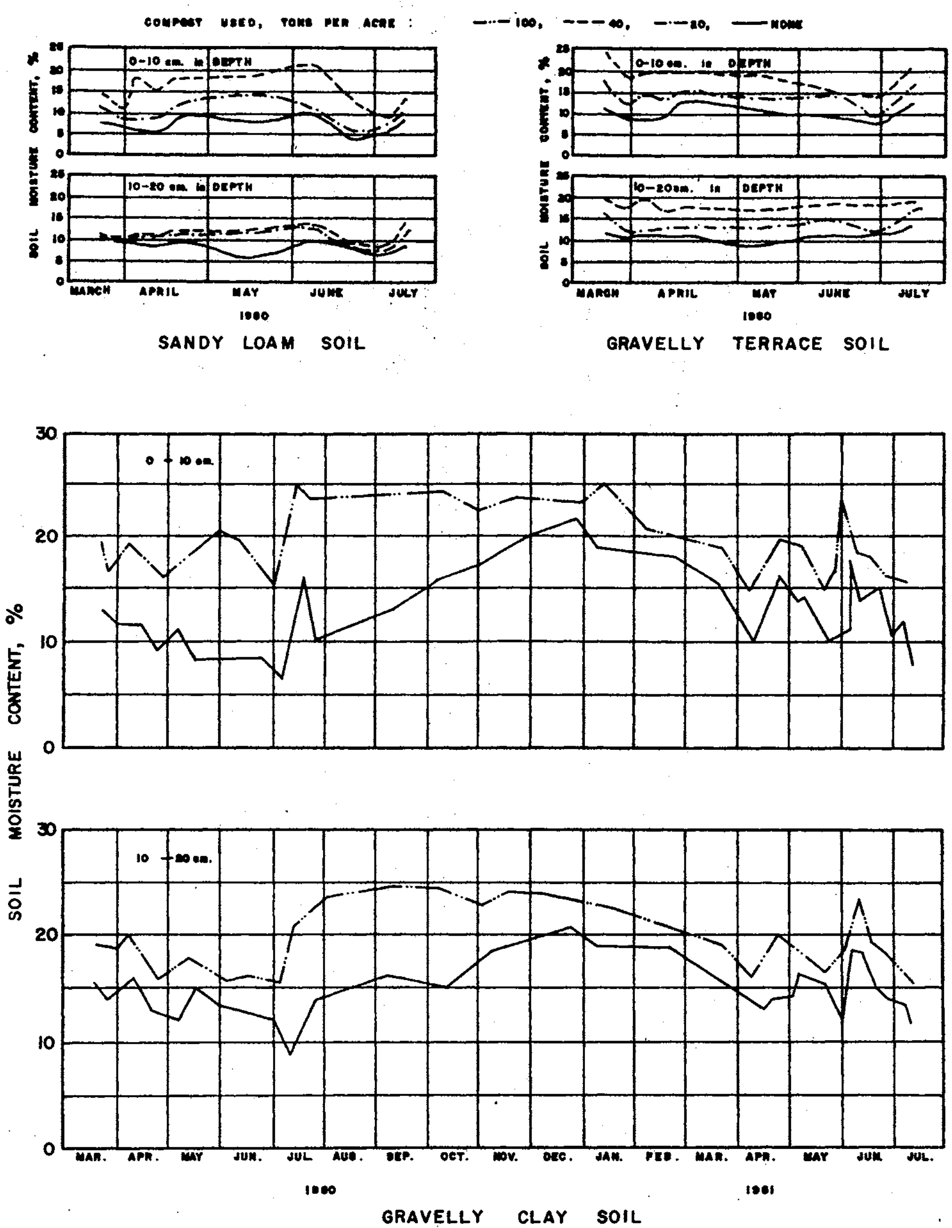


Figure 4. Effect of Compost on the Moisture Retention of Some Vineyard Soils (Reference 21)

1. Improvement in Soil Health

The following improvements in the overall health of the soil were noted as a result of applying compost:

a. In order for the soil to possess a good physical fertility, there must be a proper balance between the solids, the air, and the water in the soil pores.

b. While the ratio of pore volume in soil substance is favorable in sandy soil, some infertile soils lack the ability to retain moisture, and the pores are filled largely with air.

c. Loamy and clayey soil possess the ability to retain water, but the air may be so low that roots cannot grow.

d. A healthy, fertile soil contains soil aggregates caused by microorganisms and small animals which produce a friable soil. In such soil, there are very fine capillary pores with larger connecting pores. The micro-pores take up moisture by capillary action and store it for plant growth. The macro-pores, on the other hand, are filled with air but also become temporarily filled with water after heavy rains.

e. When compost was added to the soil, an improved soil structure occurred. The soil was more crumbly and loose.

f. There was also marked reduction in volume of solids to pore volume ratio. The effects of this reduction of solids ratio is shown at the top of Figure 5. The figure shows that the air volumes were increased greatly in the soil containing 33-38 percent moisture by weight. A phenomenon of major significance is the respiration of roots and the avoidance of damage from chlorosis. In addition, the increased pore volume led to an increase in moisture retention which, in the middle layer tested, was from 24.8 percent to 29.5 percent by weight.

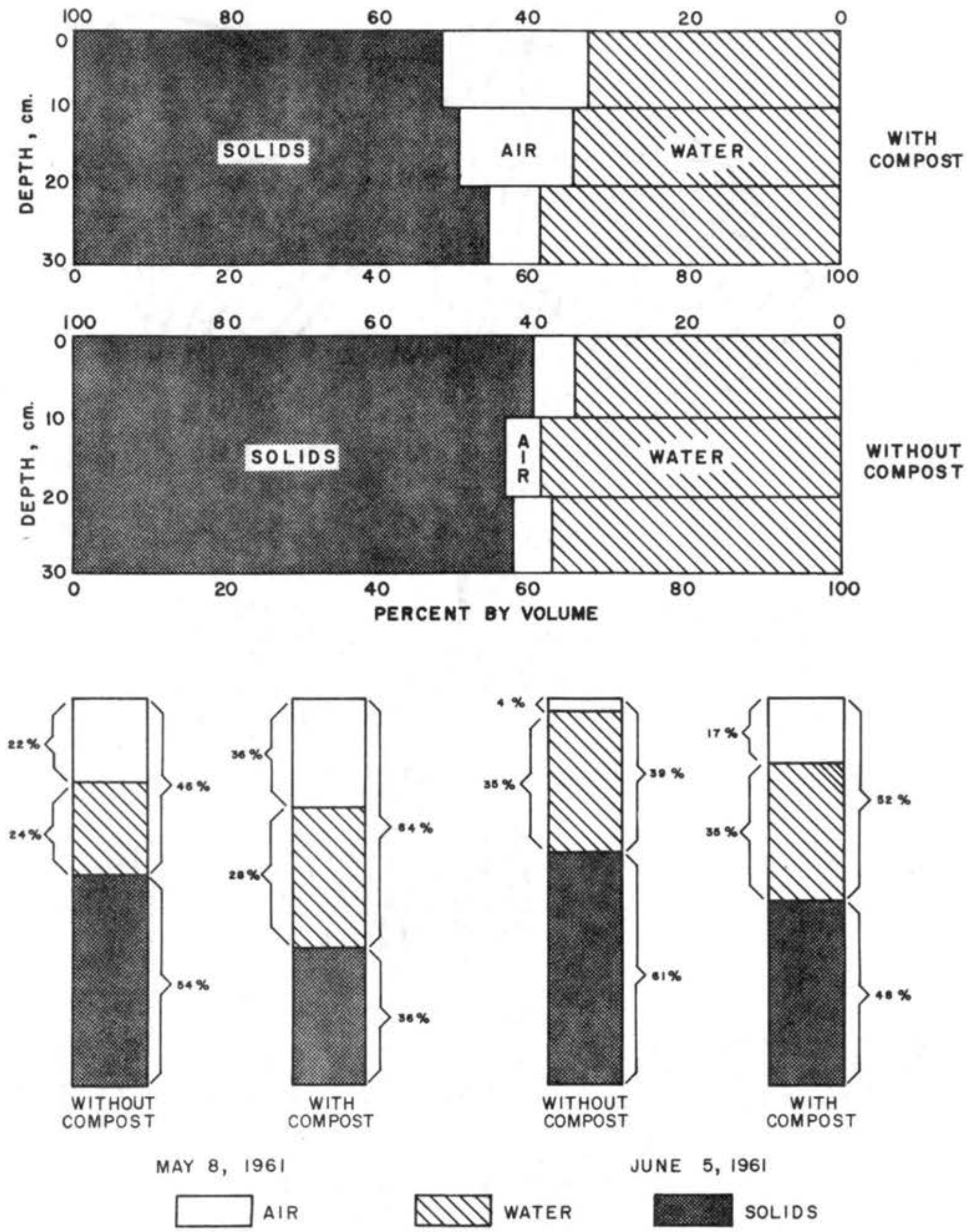


Figure 5. Effect of Compost on Soil Structure (Reference 11)

2. Reduction of Erosion

In the spring of 1961, two samples were taken four weeks apart which showed that soil structure and the various components were not constant, but varied greatly. All plots were cultivated on April 26. Compost plots were found to be much easier to work. One sample was taken on May 8, before any compaction had occurred. The analysis of this sampling is shown at the bottom left of Figure 5. Note the decrease in solids and increase in water and air. The soil held water for a longer time when treated with compost.

Samples were taken in the same plot on June 5, after the ground had been trampled during working and 3.9 inches of gentle rain had occurred. The analysis of this soil is shown at the bottom right of Figure 5. Note the water volume is the same as a result of the compaction, but the air space in the soil treated with compost is still greater. This is a phenomenon that has a significant effect on the ability of the root to obtain oxygen for growth.

3. Increase in Permeability

Permeability tests showed that water percolated through the soil treated with compost much faster than through untreated soil (21). In a period of one hour under saturated conditions, the water ran through 10 centimeter deep soil samples of 1,000 cc's volume, as shown in Figure 6. Note the increase in the amount of water that flowed through treated soil. The significance of this phenomenon may have its greatest effect in the ability of the soil to absorb water from rainfall rather than allowing it to run off. This might be very beneficial in areas where there are infrequent but heavy rains as often occur in southwestern United States.

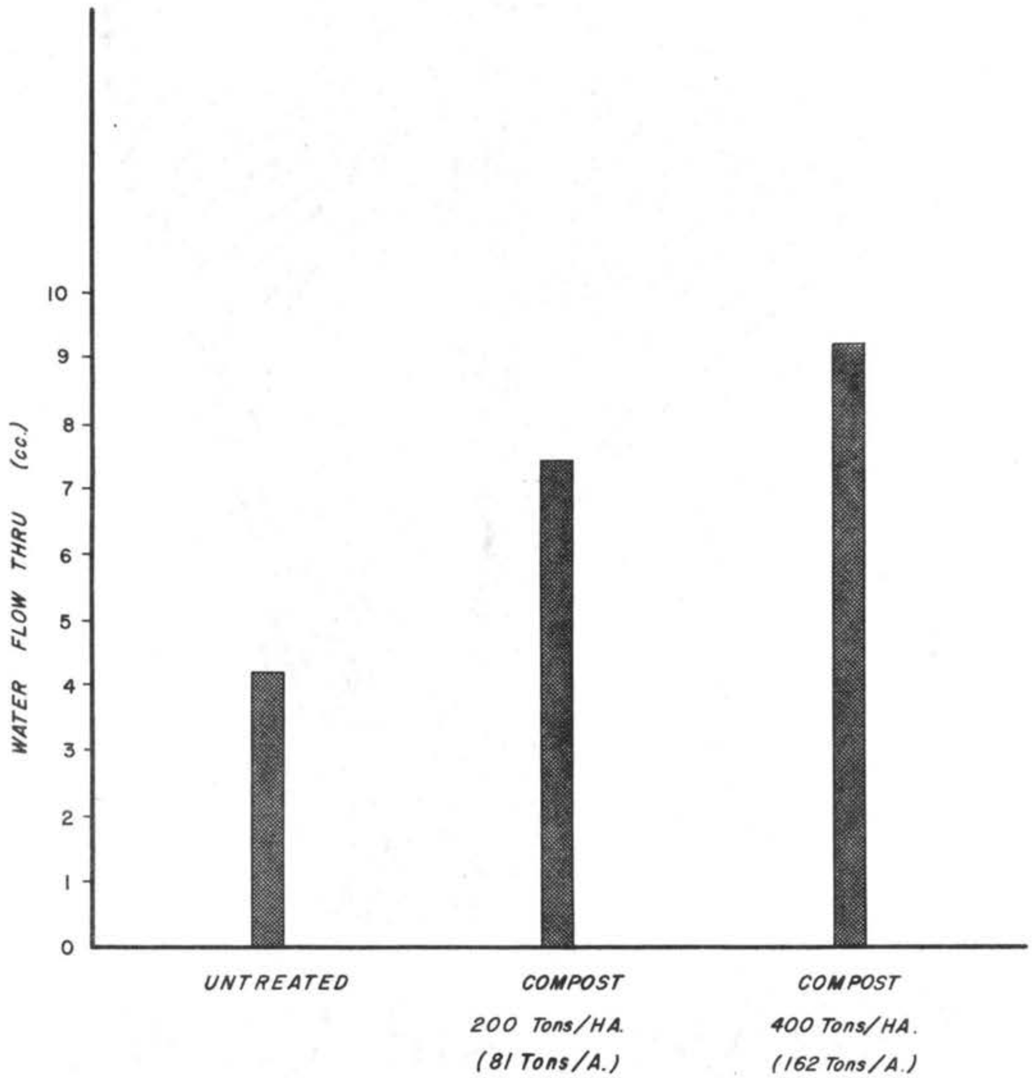


Figure 6. Permeability Tests (Reference 11)

It was also found, as a result of tests, that soil erosion was greatly reduced by compost. In May, 1960, 1.5 inches of rain fell in a two-hour period on a 30^0 slope. The comparison of the runoff of soil from these plots is shown in Table X. Note that when the soil was treated with compost, the soil erosion was reduced dramatically over that which had no compost added. Again, this phenomenon could have a significant beneficial effect in the southwest to reduce part of the heavy soil erosion from sudden, severe rain storms.

TABLE X

EFFECTS OF COMPOST TREATMENT ON RUNOFF AND EROSION*

Compost (T/ha)	Total Runoff (liters/plot)	Eroded Soil dry weight (kg/plot)	(kg/ha)	FINES (2mm) %
0 0	102.5	30.26	12,607.4	54.9
200 (80 T/A)	58.3	21.25	8,852.6	45.1
400(160 T/A)	3.9	.15	64.4	38.5

Note: Each plot consisted of 24 sq. m. of slope area
20 sq. m. of horizontal area

*Source: Banse, H. J., IRGRD, Information Bulletin #13, December, 1961.

The beneficial erosion control shown above also was verified by experimentation in Switzerland during 1958-1961. The results of this experimentation are shown in Figure 7.

As indicated, the average erosion loss from the plot treated with

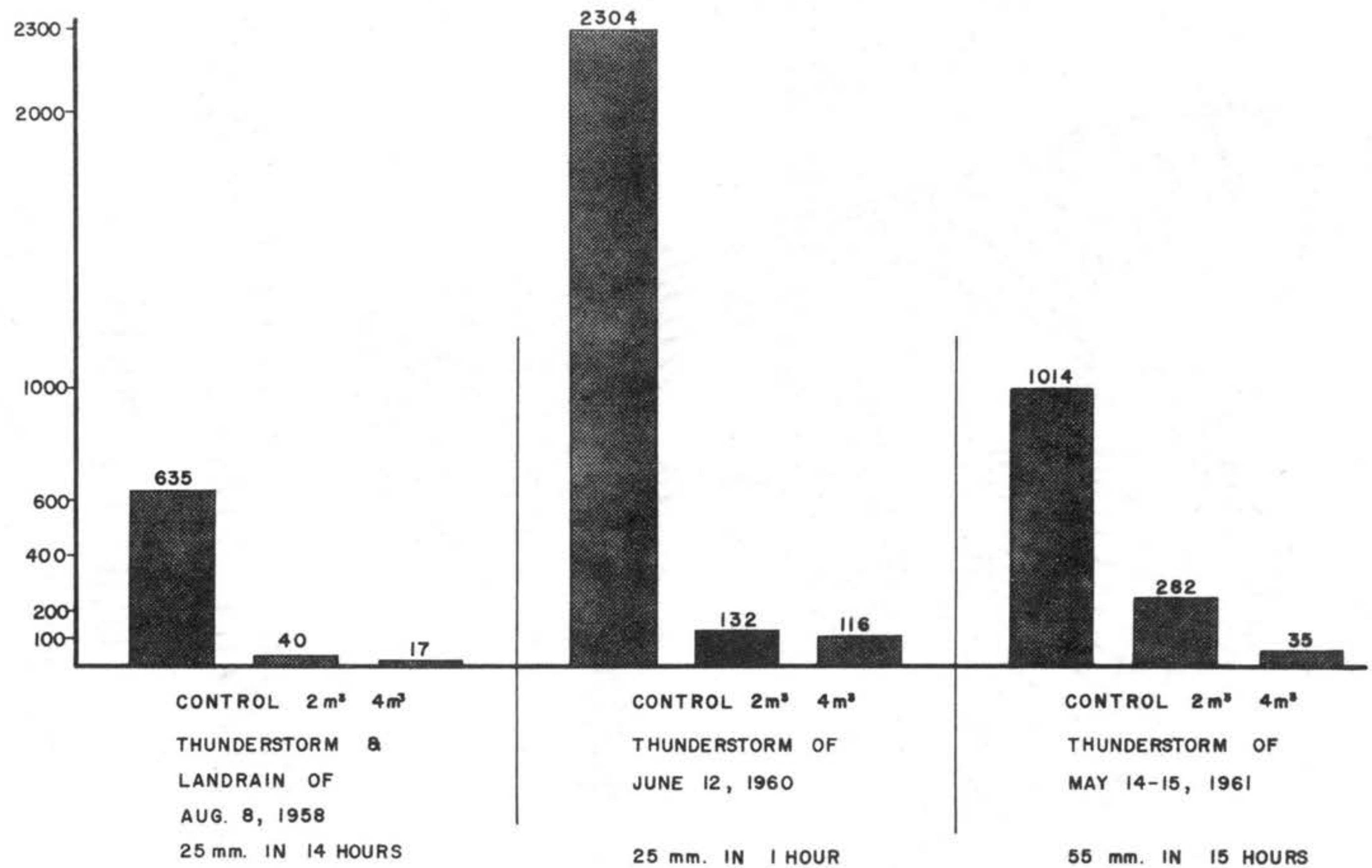


Figure 7. Effect of Compost on Soil Erosion
(Reference 22)

four cubic meters of compost per 100 square meters of vineyard amounted to only six percent of that of the untreated plot. The summary of the results of the effects of compost application obtained from the research conducted in Switzerland is as follows:

a. Improvement in soil structure with greater friability and pore volume resulting in improved moisture distribution and exchange of gases.

b. Increased moisture retention capacity combined with reduction in soil drying due to drought caused by the water-retaining property of humic substances.

c. Increased retention of plant nutrients and trace elements in the soil due to the ion exchange properties of the humus (slower and more uniform release of nutrient to the crop, reducing leaching).

d. Prevention of erosion by the addition of humus in creating a more crumbly soil texture. These effects of humus increase proportionately to its content in the soil up to a certain point. The essential aim of compost application is, therefore, in raising or at least maintaining the humus level in the soil.

e. Promotion of plant growth by providing regulated available nutrients and trace elements (fertilizing action of compost, particularly of refuse-sludge compost) and by enhancement of the micro- and macro-fauna of the soil (formation of certain organic compounds which can be assimilated by higher plants and stimulate growth; prevention of soil parasites often appearing in soil devoted to a single crop; fixation of mineral nutrient elements into a form usable by plants).

CHAPTER III

MATERIALS AND METHODS

A. General

To accomplish the objectives of this study, four columns of the same soil were used. One column was untreated, one column was treated with chemical fertilizer, the other two with raw dairy cow manure. Moisture content and movement were monitored with tensiometers placed at four depths. The water at these four depths was sampled periodically for ammonia and nitrate concentration. All tanks were sodded with U-3 Bermuda grass, and plant growth was monitored by daily measurements and by periodic cutting and weighing. The chemical oxygen demand (COD) of the water at the bottom of the columns was monitored to determine the effectiveness of the soil column in removing the COD. The data ~~was~~ were compared to determine changes in the physical, chemical, and biological properties of the soil. The soil composition was measured before and after the period of evaluation.

For the purpose of simplifying data recording, the following notation applies:

Tx/y - Tensiometer reading in tank 'x' at level 'y'.

Sx/y - Sample of water taken from tank 'x' at level 'y'.

Tank 1 (T1) was the standard with no additives.

Tank 2 (T2) contained chemical fertilizer, 60# N/acre.

Tank 3 (T3) contained 50 tons/acre of manure.

Tank 4 (T4) contained 10 tons/acre of manure initially, with 10 tons/acre added at T plus 54 days.

Level 0 was the surface of the soil.

Level 1 was three inches below the surface of the soil.

Level 2 was nine inches below the surface.

Level 3 was 15 inches below the surface.

Level 4 was 24 inches below the surface.

Level 5 was 27 inches below the surface and was the bottom of the soil.

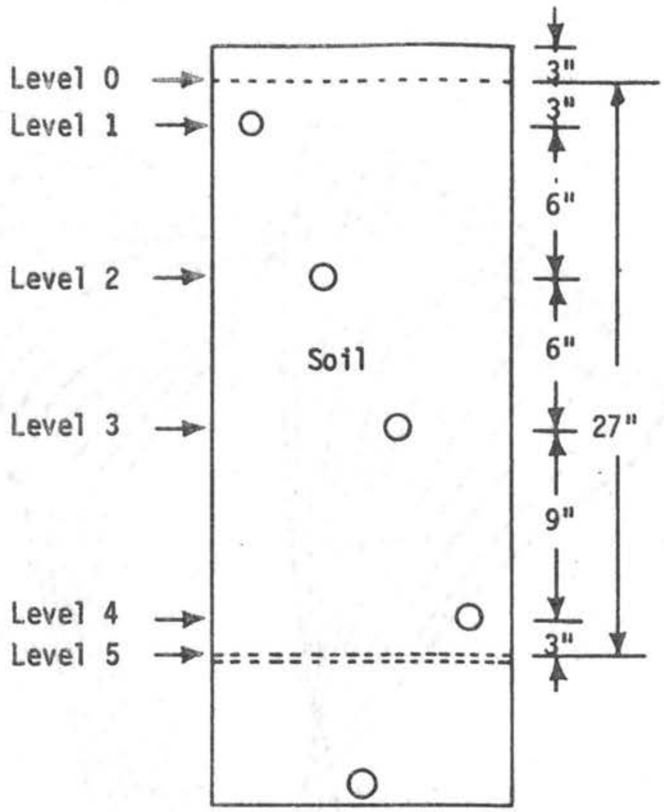
B. Apparatus

A sketch and picture of the apparatus used for this study are shown in Figure 8. This apparatus was designed and built in the lab. It was very functional in general. Some of the difficulties are discussed in detail below:

1. Tanks

The tanks were constructed of 3/8-inch plexiglass sheets fused together with dichloroethane. The tensiometers and sampling tubes were installed at the depths shown in Figure 8. The tensiometers and sampling tubes were installed in such way that maximum separation was provided between the ceramic cups of each to reduce interference.

The primary limitations in these tanks was the fact that the bottom of the column of soil had a soil-to-air interface which does not occur in nature. The attempt to duplicate the effect of subsoil was finally abandoned because of the complexity of the interactions of the soil. Since this study was primarily a comparative analysis of changes, this



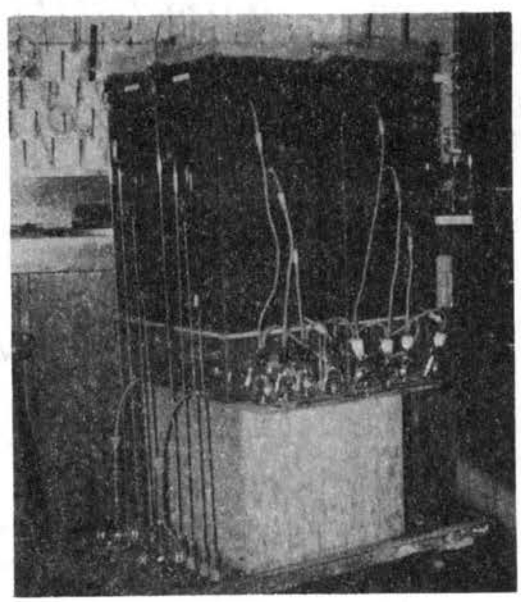


Figure 8. Test Apparatus

limitation is not considered prohibitive.

2. Tensiometers

The tensiometers were constructed by bending a 7-inch length of 3/8-inch plexiglass tubing into an L-shape, then securing a 3/8 x 1 1/8-inch porous ceramic cup to the tube, using epoxy glue. The indicator column was made by inserting a 3/32-inch nylon tube in a small hole in the plexiglass tube and sealing with epoxy glue. The bottom of the indicator tube was extended to the base of the apparatus and into a bottle of indicator fluid open to the atmosphere. The tensiometers were tested by submerging in water and applying a pressure of 5 psi to the tube and watching for bubbles. The ceramic cups were tested by applying 15" Hg vacuum to the submerged cups and accepting only those that allowed at least 1 ml/min of water to flow through (cup conductance).

Tetrabromoethane ($C_2H_2Br_4$) stained with granular iodine was used for the indicator fluid during most of the study. Extreme care was required to prevent the fluid from coming in contact with the plexiglass tubing, since bromoethane dissolves plexiglass. This fluid was acceptable, but the color faded after a few weeks and the interface between the fluid and the water in the tensiometer was difficult to find for measurements.

Mercury was used for the indicator fluid when the unit was subjected to drought conditions during period V of the study. Less accuracy is achieved with the mercury because of the small daily changes in the fluid height, and the limitation of the tensiometers seems to be about 22-24 inches of mercury, or slightly less than one atmosphere of moisture tension. Bubbles forming at these readings interfere with the column height, even when cooled, boiled water was used in the tensiometers.

3. Sampling Tubes

The water sampling tubes were made by gluing a porous ceramic cup as described in section 2 above to a 6-inch length of 3/8-inch (O. D.) plexiglass tubing. These samplers were then tested by submerging them in water and applying 20 psi pressure to the tube. Only those which did not bubble were used. Cup conductance tests were carried out as in section 2 above, and only those with a conductance of 1 ml/min or greater were used.

These tubes were satisfactory, but some did fail at the epoxy glue point. Four hours were required to draw samples when the soil was saturated, and 12-18 hours required when the moisture deficiency had reached 300 cm of water. To draw the water from the soil, 15" Hg vacuum was applied to stoppered flasks into which the water could drain by gravity flow.

4. Lighting and Heating

A bank of 'grow lites' was used to provide a light intensity of 200 footcandles at the surface of the soil. These lights were automatically timed to provide light 14 hours per day. The temperature in the room was controlled to provide a range of temperatures between 28°C at night to 34°C during the day.

C. Materials

1. Soil

The soil selected for the study (clay loam) was taken from an uncultivated field four miles east of Stillwater, Oklahoma. The field had broom sage as primary cover. The soil analysis is discussed in detail in Chapter IV.

The four tanks were placed on a vibrator and alternately filled with shovels-full to provide maximum uniformity. When the tanks were filled to three inches below the top of the tank, the soil was watered with three inches of water and vibrated for 15 minutes. The tanks were then allowed to set for 12 hours. The vibrator was turned on again for five minutes to further settle the soil. The tanks were then refilled to three inches below the top with soil, watered with three inches of water, vibrated for 30 minutes, then allowed to set for 15 days before adding the fertilizer and manure. This method of filling was selected to provide a discontinuity intended to simulate the discontinuity which occurs when the soil is cultivated.

2. Manure

Fresh dairy cow manure that had been piled in the open for two days was used. The manure was throughly mixed to ensure maximum uniformity. The manure was weighed and that which was not used immediately was frozen in 10 ton/acre packages. The analysis of the manure is shown below:

N (% of dry wt)	P (PPM)	K (PPM)	COD (PPM)
2.05	8,968	25,875	58,850

CA (PPM)	Mg (PPM)	Fe (PPM)	Zn (PPM)	Mn (PPM)
3,100	4,350	3,125	112	218

3. Fertilizer

The fertilizer applied was ammonium phosphate, 18-46-0.

D. Methods

1. Apparatus Preparation

Four tanks with a 27-inch column of soil were used for the study. When it appeared that the soil had settled, the tensiometers were inserted horizontally, six inches into the soil. The sampling tubes were inserted at the same level at an angle to allow gravity flow of the water drawn into the cup. The water was collected in small flasks as shown in Figure 8. A rubber stopper between the plexiglass tubing and the wall of the tanks sealed the tank against moisture loss and permitted the tubes to flex as the soil settled.

When the soil was dry enough to cultivate, the fertilizer and manure were added to the respective tanks and the top three inches of soil in all tanks was cultivated. The fertilizer was added to T2 at the rate of 60 pounds of nitrogen per acre. The manure was added to T3 and T4 at the rate of 50 tons/acre and 10 tons/acre, respectively. T1 was used as the standard or blank with no additives except water.

Time during the study was measured from the day the soil was treated with the fertilizer and manure, or T-day. The time of the study was further divided into periods, each period including a watering, a growing period, and a grass cutting.

2. Reaction Prior to Planting

The first phase of the study from T to T+27, or period 1, evaluated the response of the soil after fertilizer and manure had been applied but before the grass was planted. This period corresponds to the actual time between soil preparation and planting, or while the land is idle. The response during this time probably indicates the response that can be expected from soil that is only partially covered by a crop, such as the early days of corn.

The tanks were watered with three inches of water on T+5. In all cases, the waterings were accomplished by pouring one inch of water alternately into the four tanks until each had received three inches. Tap water was used in all cases. The infiltration rate was determined by measuring the volume of water remaining in the tanks with increasing time. Water in the soil was sampled for nitrate concentration on T+5 and T+6, and for ammonia concentration on T+9 and T+10. The soil surface conditions were noted during this period.

The tanks were watered again on T+26 with three inches of water. Infiltration rate and permeability were again measured. The water in the soil was sampled for nitrate and ammonia concentration on T+26 and T+27. The moisture tension in the soil was measured daily by recording the tensiometer readings.

3. Reaction After Planting

The next phase of evaluation was from T+28 to T+88 and included periods II, III, and IV. All tanks were planted with U-3 Bermuda grass sprigs on T+28. Daily tensiometer readings were recorded. When any tensiometer had reached its limit, the tanks were all watered with three inches of water. This occurred three times during this phase--at T+54, T+71, and T+88. Sampling of the water in the soil was conducted at various times. The pattern of sampling was varied to detect any variation in concentration of the nitrates and ammonia. Continuous sampling was not done because it was desired that minimum disturbance of the moisture pattern occur.

The height of the tallest sprig of grass was measured frequently to check for correlation between growth and biological degradation of the additives in the soil. Just prior to each watering, the grass was cut to the level of the tank (approximately 3-3¼ inches remaining). The grass was weighed wet, dried at 103^{o}C for 24 hours, and weighed again. Protein content of the dried grass was then determined.

The reduction of the COD of the manure by the soil was measured by measuring the COD of the water that flowed through the tanks, as well as the COD of the water at levels 3 and 4.

During this phase it was noted that roots were dying at the edge of the tanks because of the light, and that a rapidly growing green substance, presumed to be algae, was growing between the tank walls and the soil. To prevent both from occurring, the tanks were surrounded on all sides with paper to block the light.

At T+54, 10 ton/acre of manure was added to T4 by dissolving the manure in the first inch of water added during the watering process.

4. Reaction During Drought Condition

Beginning with T+89, period V, the tanks were not watered thereafter to evaluate moisture retention and growth under drought conditions. The indicator fluid in the tensiometers was changed to mercury to extend the range of the tensiometers. Daily tensiometer readings and tallest sprig measurements were made during the period, normally both morning and night. Three samplings of the nitrate content of the water in the soil was made. The concentration of the ammonia in the soil was decreased to the point that tests were not sensitive enough to detect other than a trace. Therefore, ammonia content measurements were discontinued during this period.

The grass was cut and weighed at the end of the period. Soil samples to determine soil composition and moisture properties were taken at the end of this period. Root growth was also observed as the soil was removed.

E. Experimental and Analytical Procedure

1. Nitrate-Nitrogen

The nitrate concentration of the samples was determined using the Brucine Method, as explained in Standard Methods, Section 213C (18). The limitations of this test are recognized. However, since the concentration of nitrate in the sample was high, the accuracy of the test is considered adequate for this comparative study.

2. Ammonia-Nitrogen

The ammonia-nitrogen concentration was determined by a method developed by Niss and described by Ecker and Lockhart (32). Two reagents were used. Reagent A contained: 4.7 grams sodium citrate, 1.7 grams citric acid, 9.6 grams phenol, all dissolved in distilled water and diluted to 480 ml. Reagent B contained 6.0 grams boric acid, H_3BO_3, 8.0 grams sodium hydroxide, 30.0 ml commercial Clorox bleach, all dissolved in distilled water and diluted to 200 ml. To 1.0 ml samples were added 5.0 ml of Reagent A and 2.0 ml of Reagent B. The samples were mixed, heated in a boiling water bath for five minutes. The samples were then cooled rapidly with ice water until they were at room temperature. The optical density of the sample was then measured at a wavelength of 615 millimicrons against a reagent blank using a Bausch and Lomb Spectronic 20. The standard curve was developed using a standard solution of 500.0 mg/l of ammonium sulfate, $(NH_4)_2SO_4$, (136.2 mg/l NH_3-N), diluting to various known strengths and measuring the percent conductance.

The reagents used for this test may be made in advance, but it is very important that they be thoroughly agitated prior to each use.

3. Chemical Oxygen Demand (COD)

The COD of the effluent at levels 3, 4, and 5 and the COD of the raw manure were determined using the procedures listed in Section 220, Standard Methods (31).

4. Moisture Content

Moisture content in the soil at the various levels was determined by measuring the height of the indicator column and converting this reading to soil moisture tension expressed in centimeters of water. This moisture tension was then converted to moisture content using moisture release curves. Enough core samples were taken to provide moisture release data for 0.1, 0.33, 0.5, 1, 5, and 15 atmospheres. The 15 atmosphere data was not needed, since the limit on the tensiometers proved to be about one atmosphere. It was later discovered that more moisture release data at pressures between 0.05 and 1.5 atmospheres would have added accuracy to the moisture release curves.

5. Soil Analyses

All soil analyses were conducted by the Soils Laboratory, Agronomy Department, Oklahoma State University, Stillwater. The soil was analyzed at the beginning of the study and at levels 0, 2, and 4 at the end of the study, 120 days after treatment.

CHAPTER IV

RESULTS

A. Soil Moisture

1. Water Infiltration Rate

Figure 9 is a plot of the infiltration rates of each of the soil columns as a function of the time elapsed after the treatments were added. As can be seen, the response of all of the tanks was about the same for the first two waterings. T1 exhibited a general increase throughout the duration of the study. T2 also increased gradually throughout the study, except during the final period when a colony of ants made vertical paths in the soil that allowed water to flow more rapidly as long as it was ponded on the surface. The dotted line in Figure 9 is an estimate of what the infiltration rate was disregarding the effects of the ant paths.

The infiltration rate in T3 increased throughout the study at a greater rate than T1. During the last two periods (after T+54) this rate exhibited a marked increase over both T1 and T2.

The infiltration in T4 decreased during the third watering, when the additional 10 tons/acre of manure was mixed in the water and applied to the soil. However, during the last two waterings, the infiltration rate increased sharply and exceeded all others, including T3.

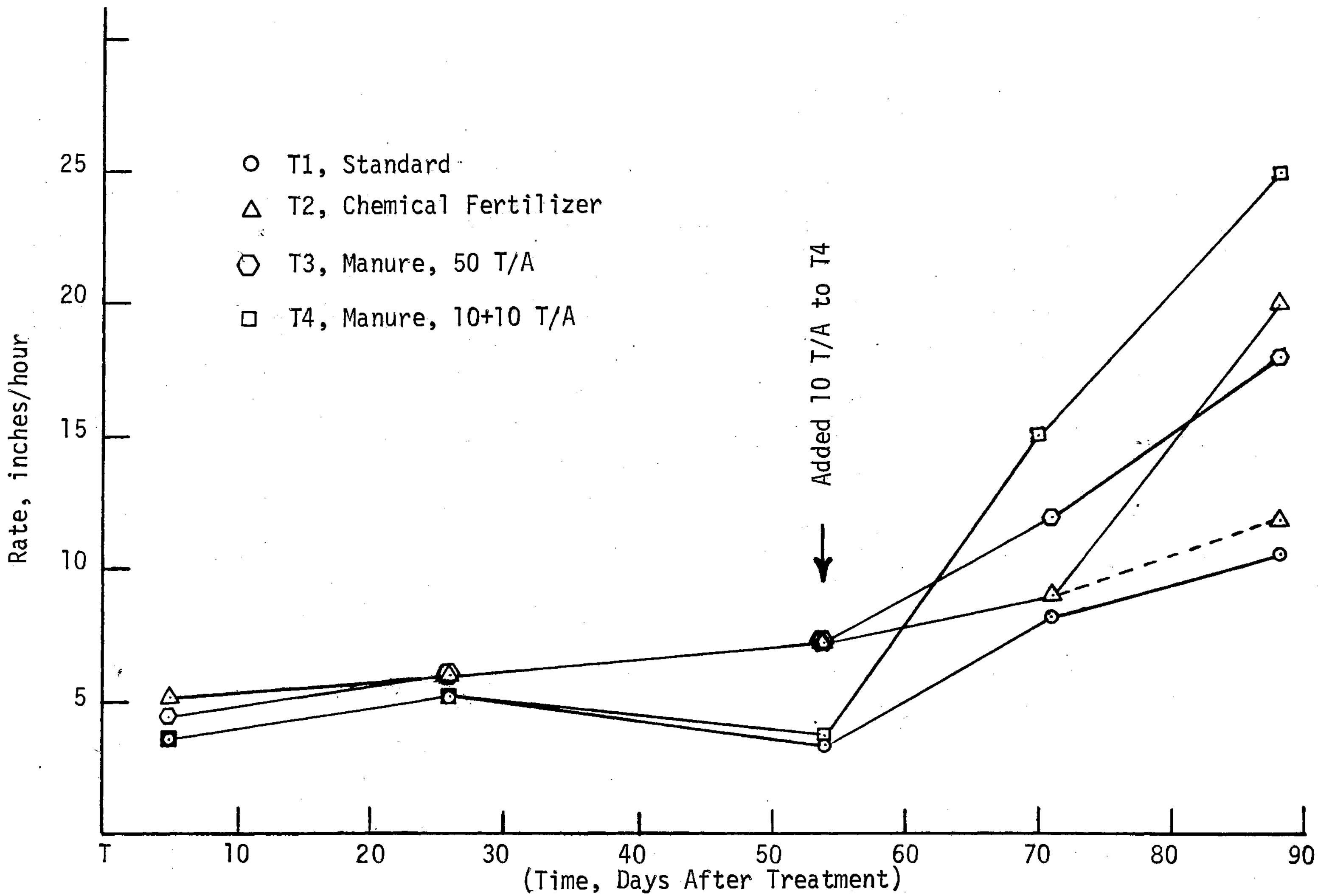


Figure 9. Water Infiltration Rates

2. Water Percolation Rate and Free Water

Figure 10 is a plot of the rate of movement of the water through the soil of the four test columns. The percolation rate is plotted as a function of time measured from the day the tanks were treated with manure and fertilizer. Note that all tanks exhibited a similar pattern until T+54, with T2 having a slightly greater rate than the others. At the fourth and fifth waterings, all rates increased, including the standard, T1. The curve for T2 is shown with a solid line for the actual measured value and a dotted line for the estimated value had it not been for vertical paths, made by ants, which permitted rapid movement of the water as long as there was ponded water in the tank.

Note the difference in the reaction of T3 and T4 during the last two waterings. The percolation rate in T3 increased less than standard, while T4 increased significantly more than standard. This difference occurred after the addition of 10 tons/acre of manure to T4 during the watering at T+54. The amount of free water expressed as percent of standard is shown below.

No. of Watering	Percent of Standard		
	T2	T3	T4
1	108	105	106
2	104	123	99
3	104	104	89
4	104	102	109
5	102	95	100

Figures 11A through 11E are plots of the free water, or effluent, from the bottoms of the tanks as a function of time measured from the moment water was ponded in the tanks. Note that the relation of T2 with the standard was essentially unchanged throughout the study, and that more free water was measured in T2 than the standard, T1.

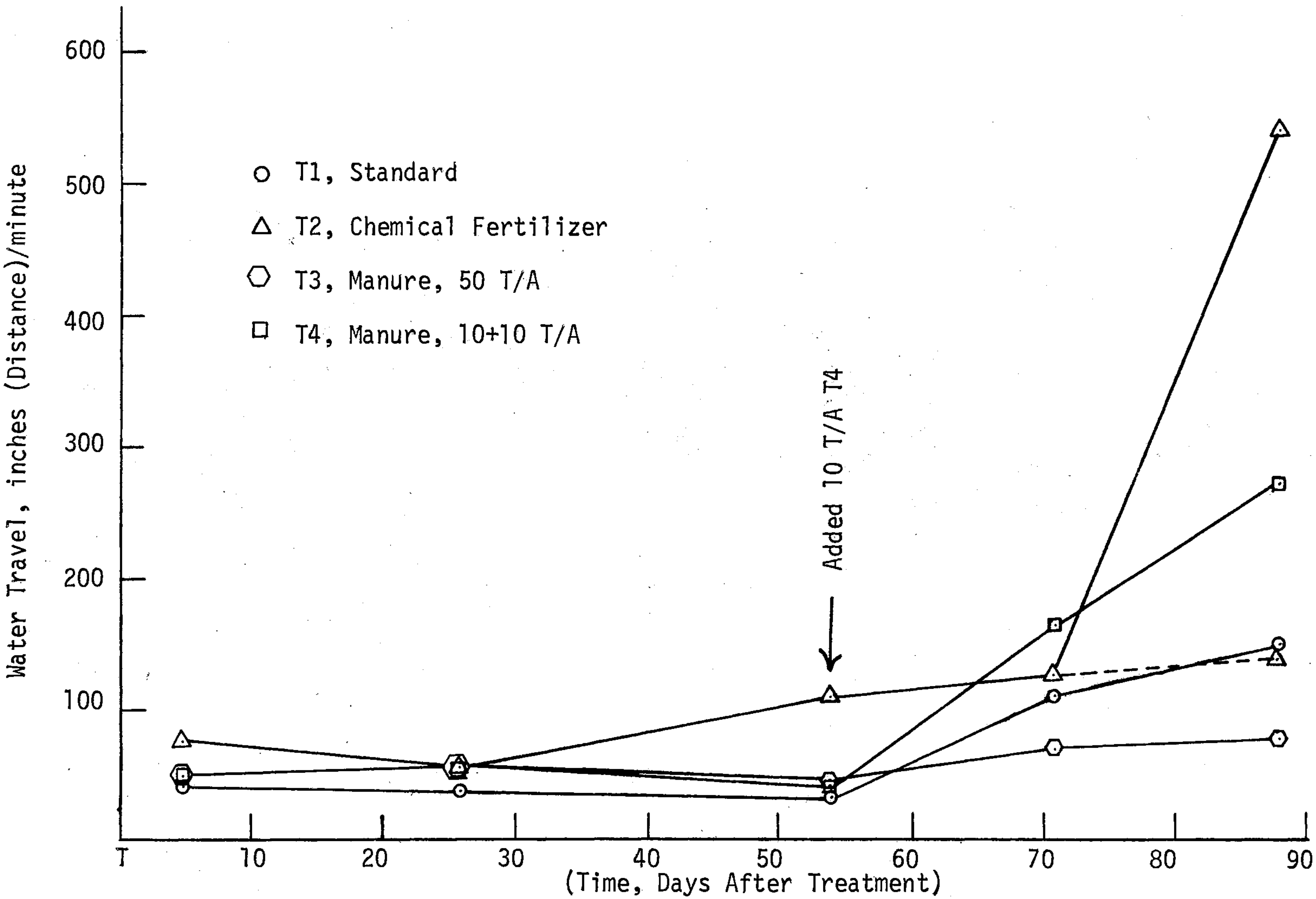


Figure 10. Rate of Water Percolation

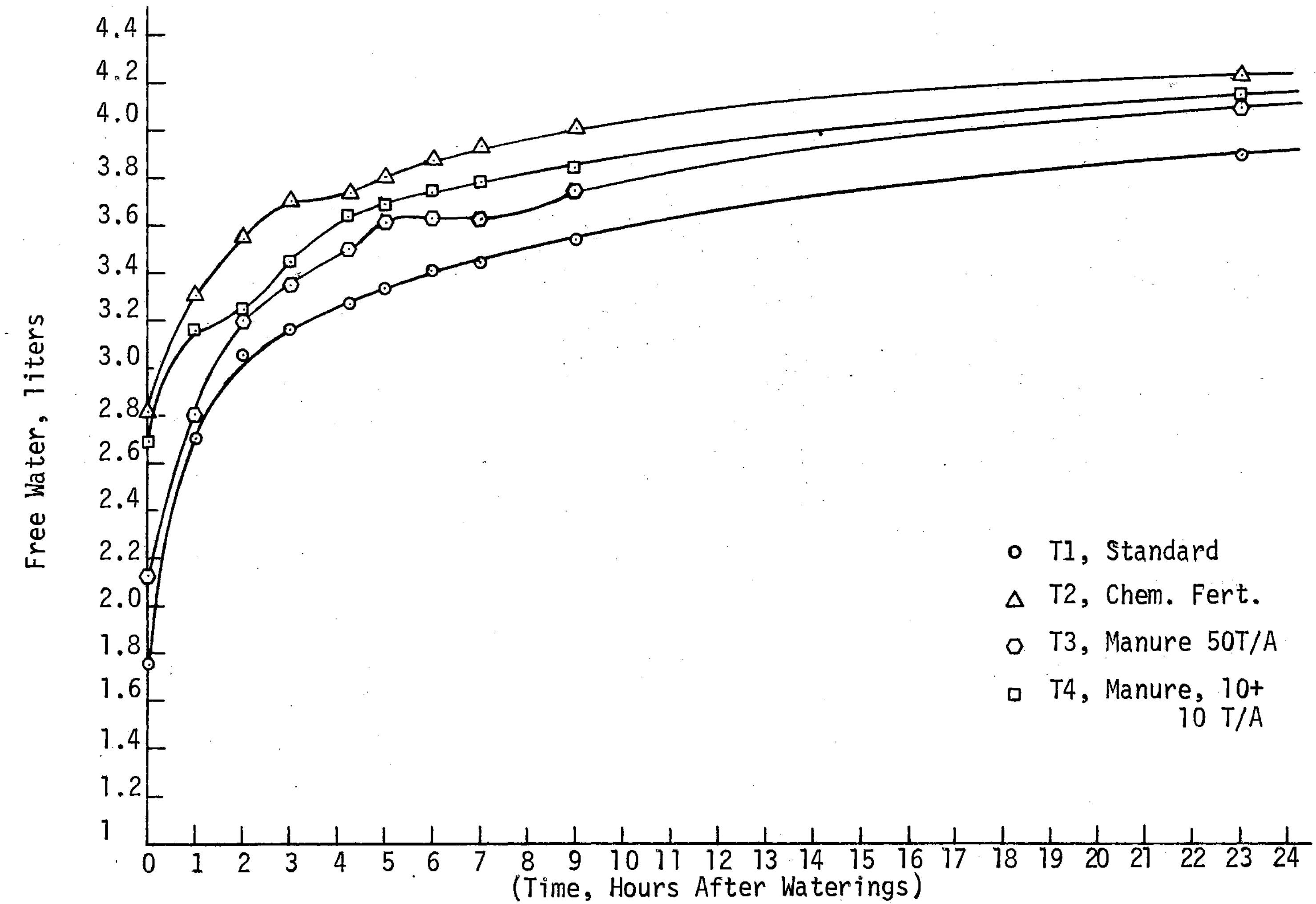


Figure 11A. Amount of Free Water, First Watering

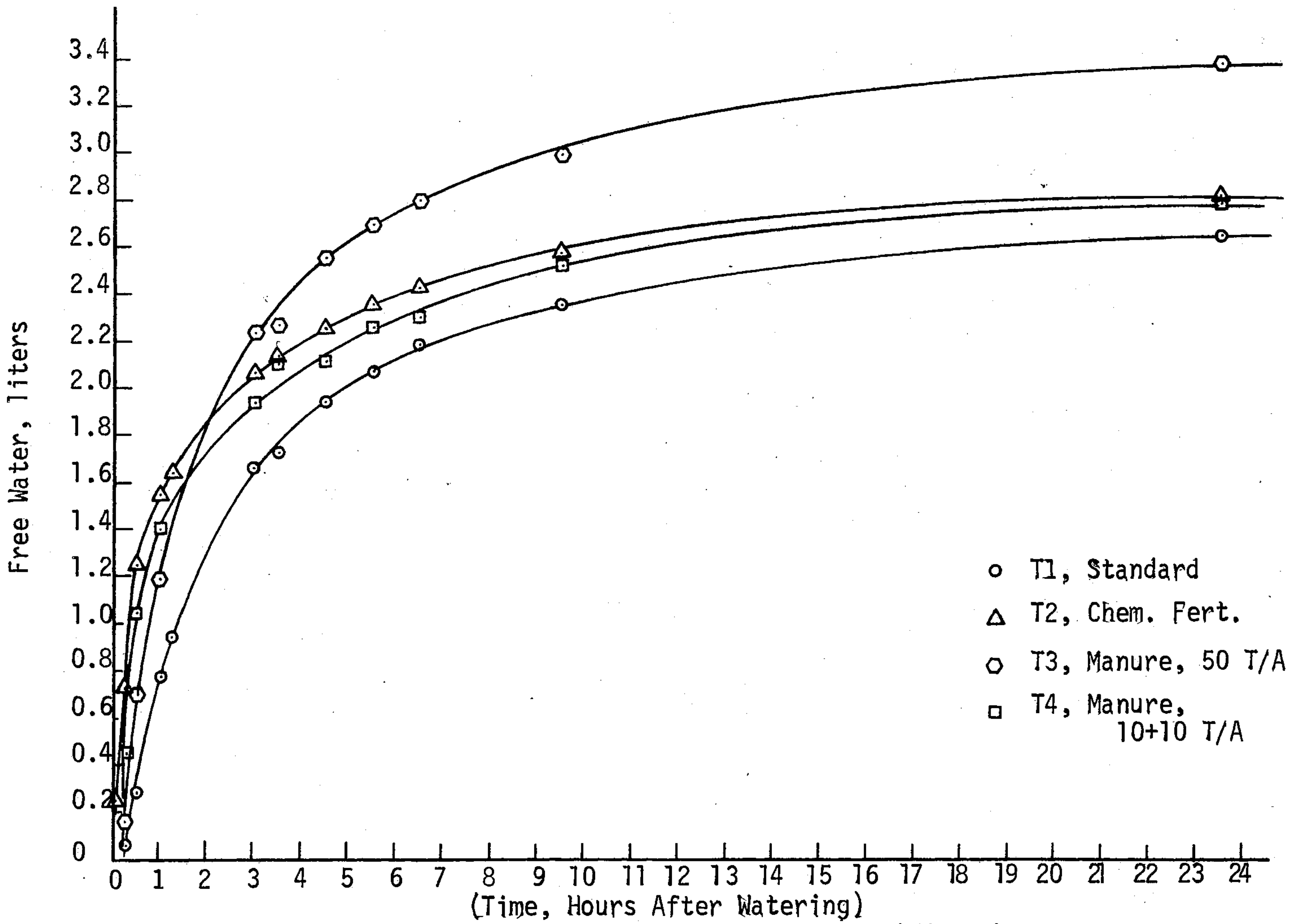


Figure 11B. Amount of Free Water, Second Watering

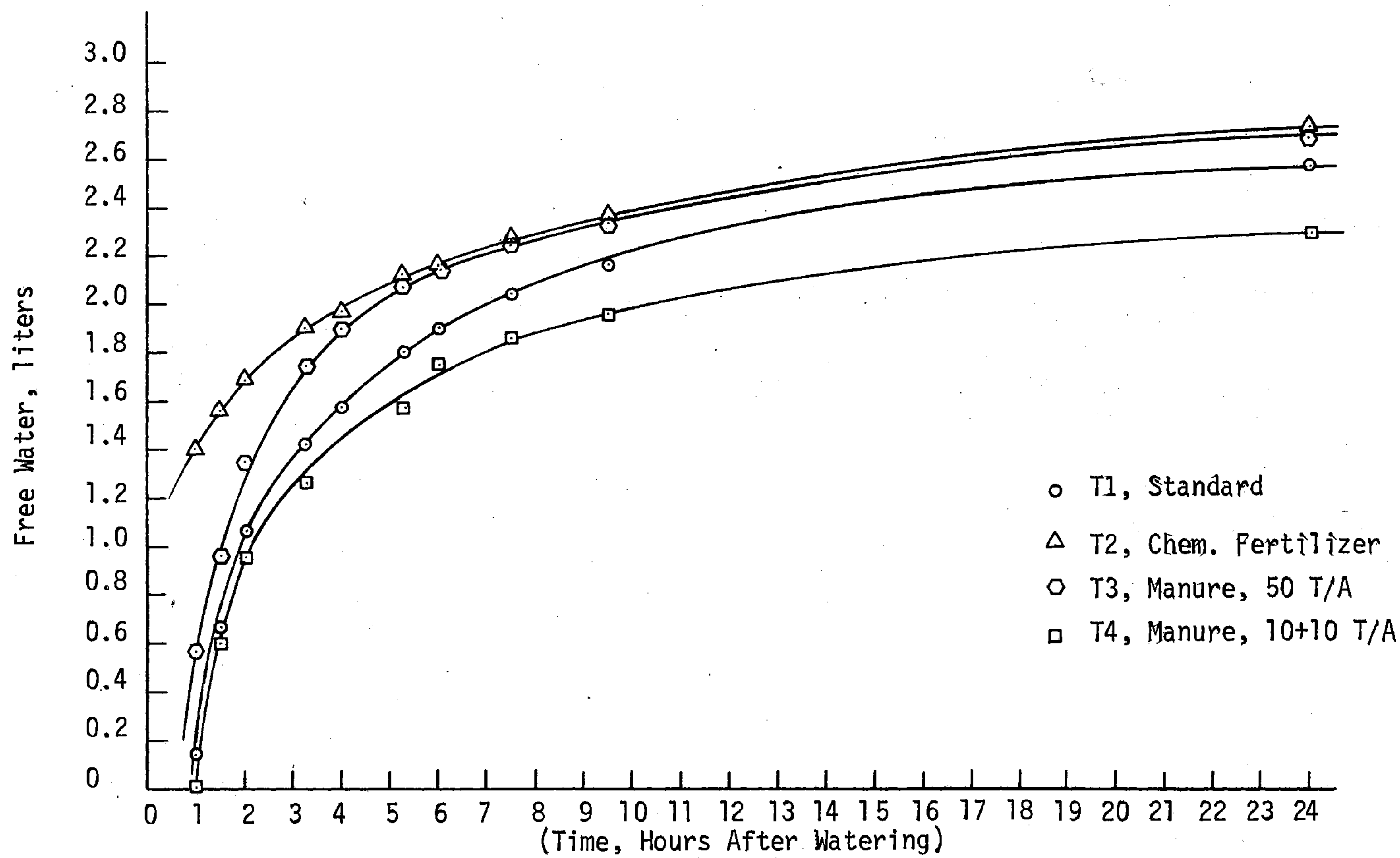


Figure 11C. Amount of Free Water, Third Watering

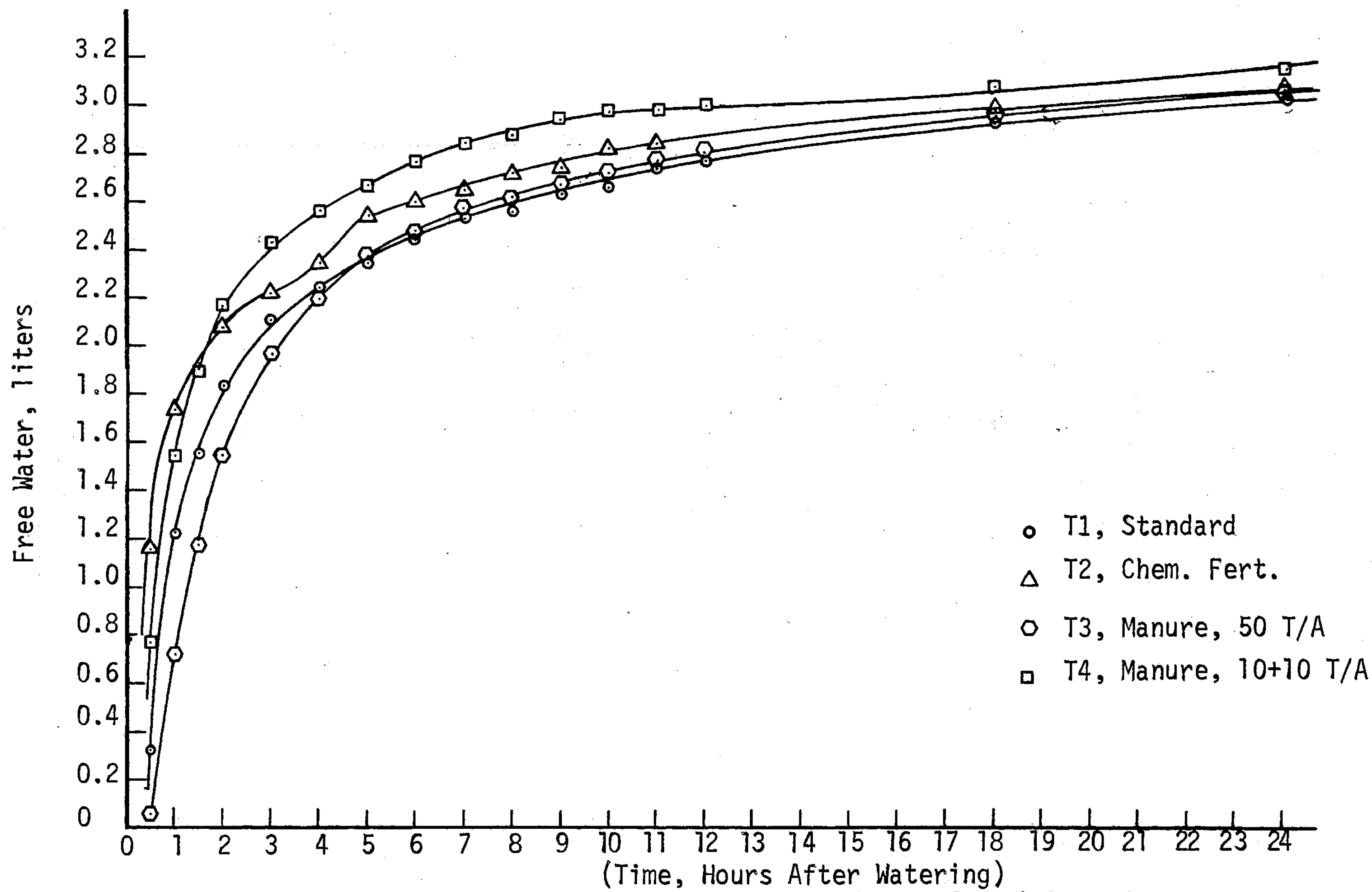


Figure 11D. Amount of Free Water, Fourth Watering

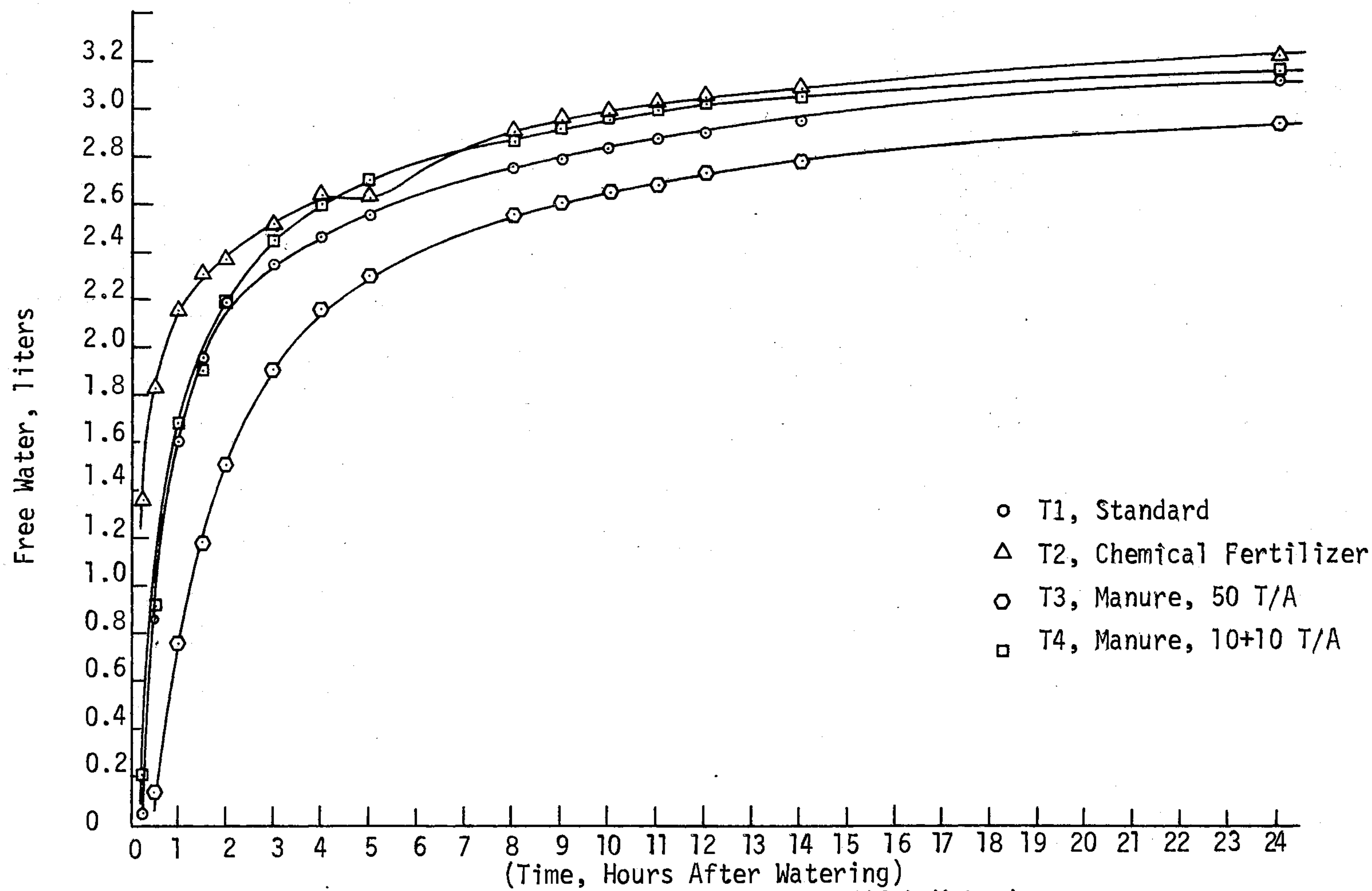


Figure 11E. Amount of Free Water, Fifth Watering

The relationship of T3 to the standard varied considerably, indicating a change in the soil as a result of the application of the manure. The amount of free water in T3 at the first watering was slightly more than in T1, increased to significantly more at the second watering then began a gradual decrease during succeeding waterings until the free water in T3 was significantly less than in T1 at the fifth watering.

T4 exhibited even more oscillation than T3, although not as great in magnitude. Note that the amount of free water in T4, with respect to T1, decreased at waterings 2 and 3, increased at watering 4, then decreased at watering 5. The additional manure was added to T4 during watering 3 at T+54 days.

3. Moisture Tension and Moisture Content

Figures 12A through 12H show the moisture tension. Note that T2 is always higher than T1, and that T3 is always lower than T1. T4 moisture tension oscillated. During period II, tension in T4 began lower than T1 but crossed over. During period IV, the opposite was true; the tension began higher, crossed over, then went lower. During period III and period V, tension in T4 was consistent and well below T1 (10 tons/acre were added to T4 at the beginning of period III).

The greatest contrast in moisture appears between T2 and T3. The moisture tension in T2 was three to four times the tension in T3.

It is also noticeable that the moisture tension did not increase in T3 and T4 during the night, when the grass was not growing. This began to be especially noticeable during periods IV and V. This phenomenon occurred in T1 and T2, but not nearly so noticeably and there was no time when tension did not increase some during the night in these two tanks.

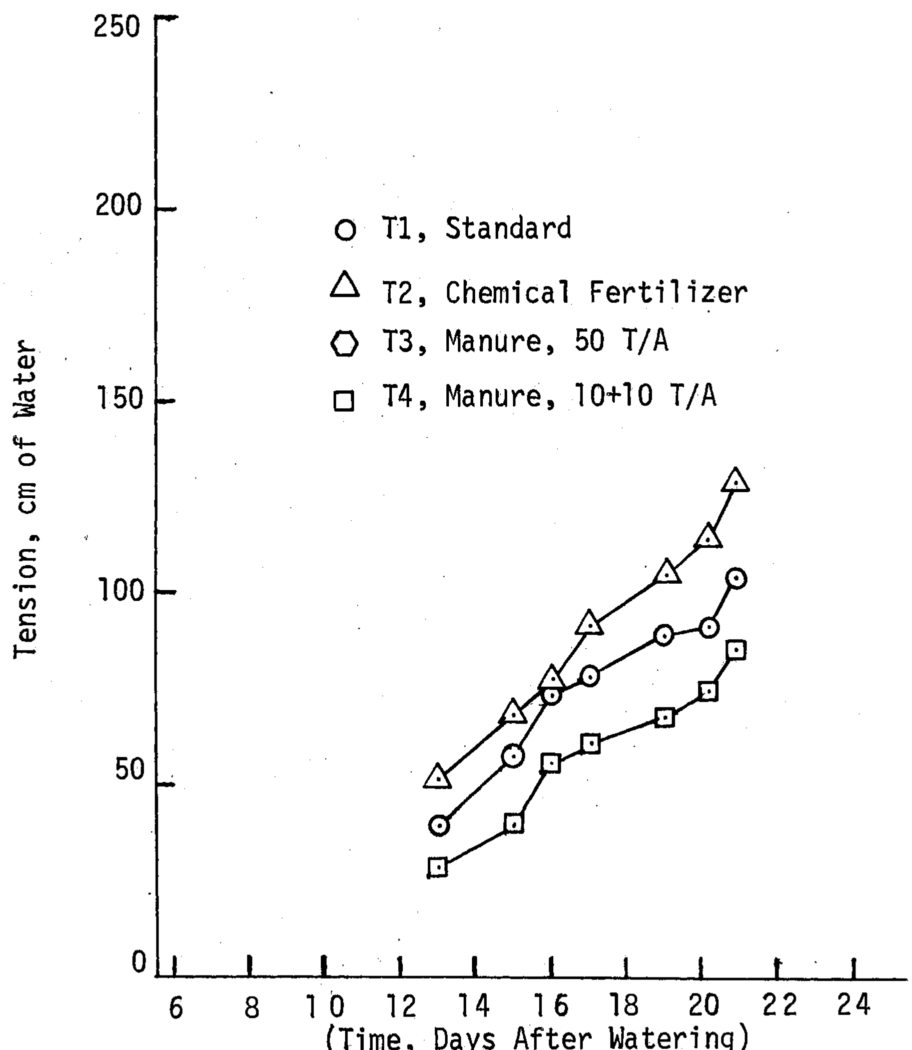


Figure 12A. Moisture Tension, Period I, Level 1

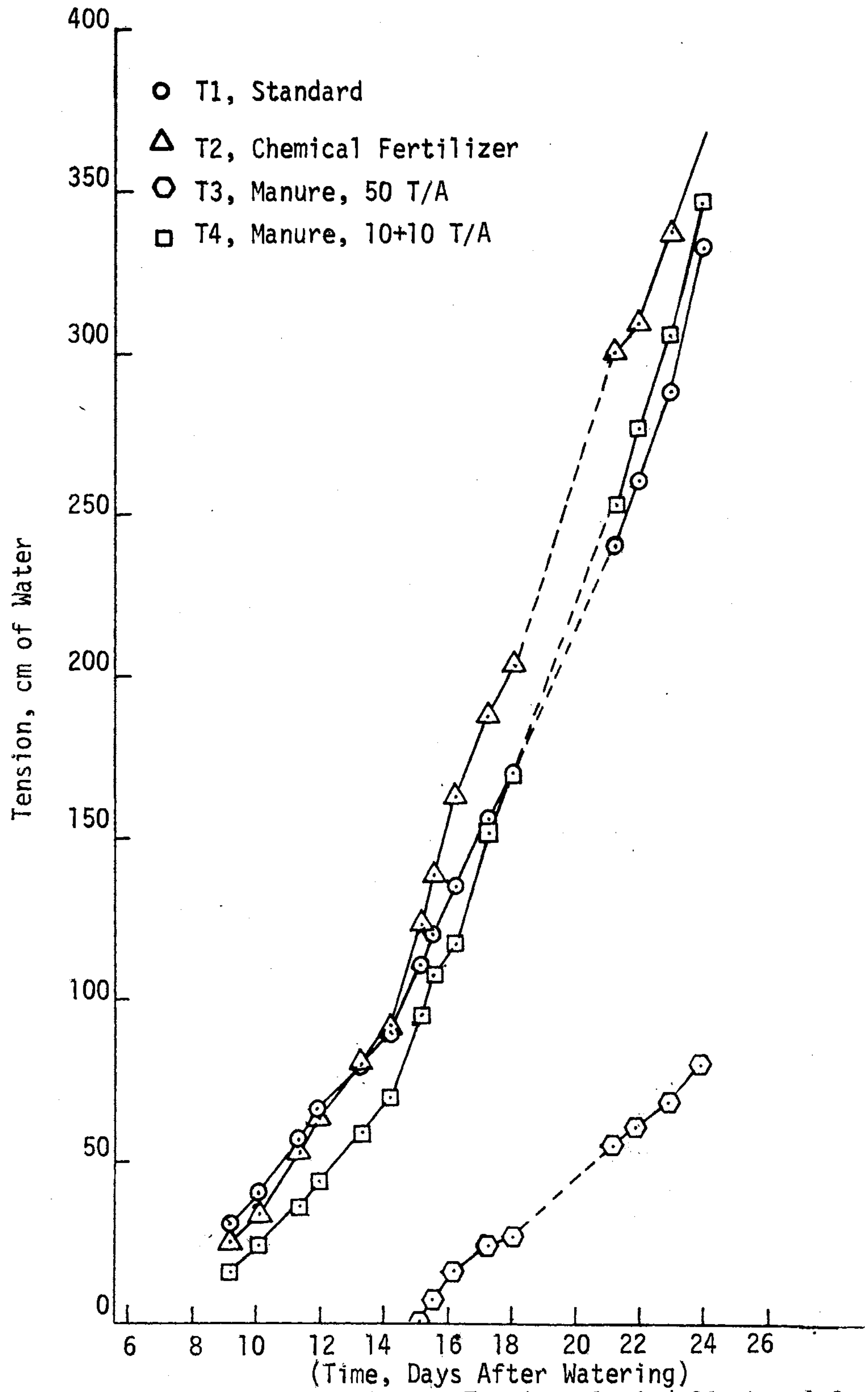


Figure 12B. Moisture Tension, Period II, Level 1

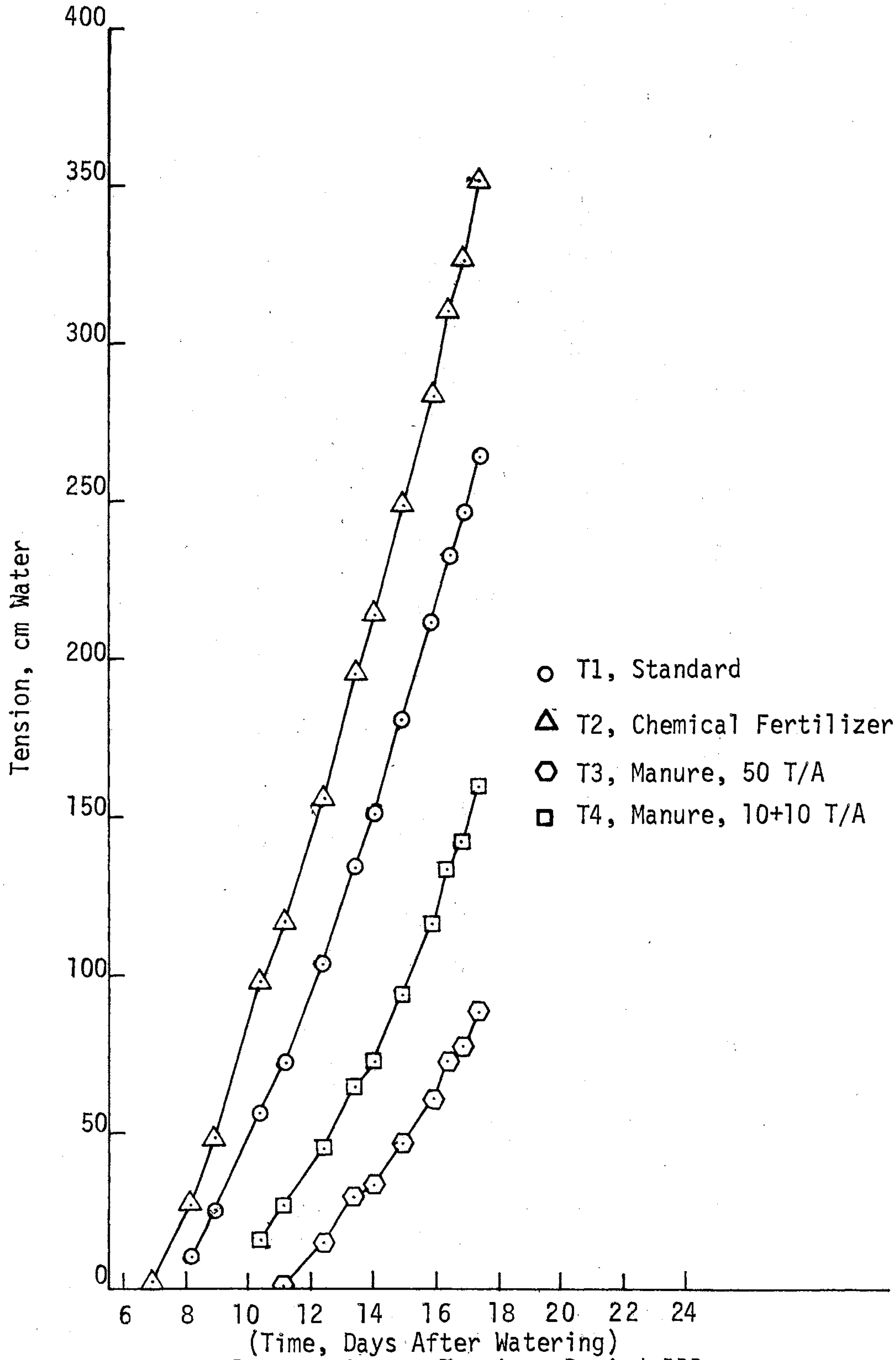


Figure 12C. Moisture Tension, Period III, Level 1

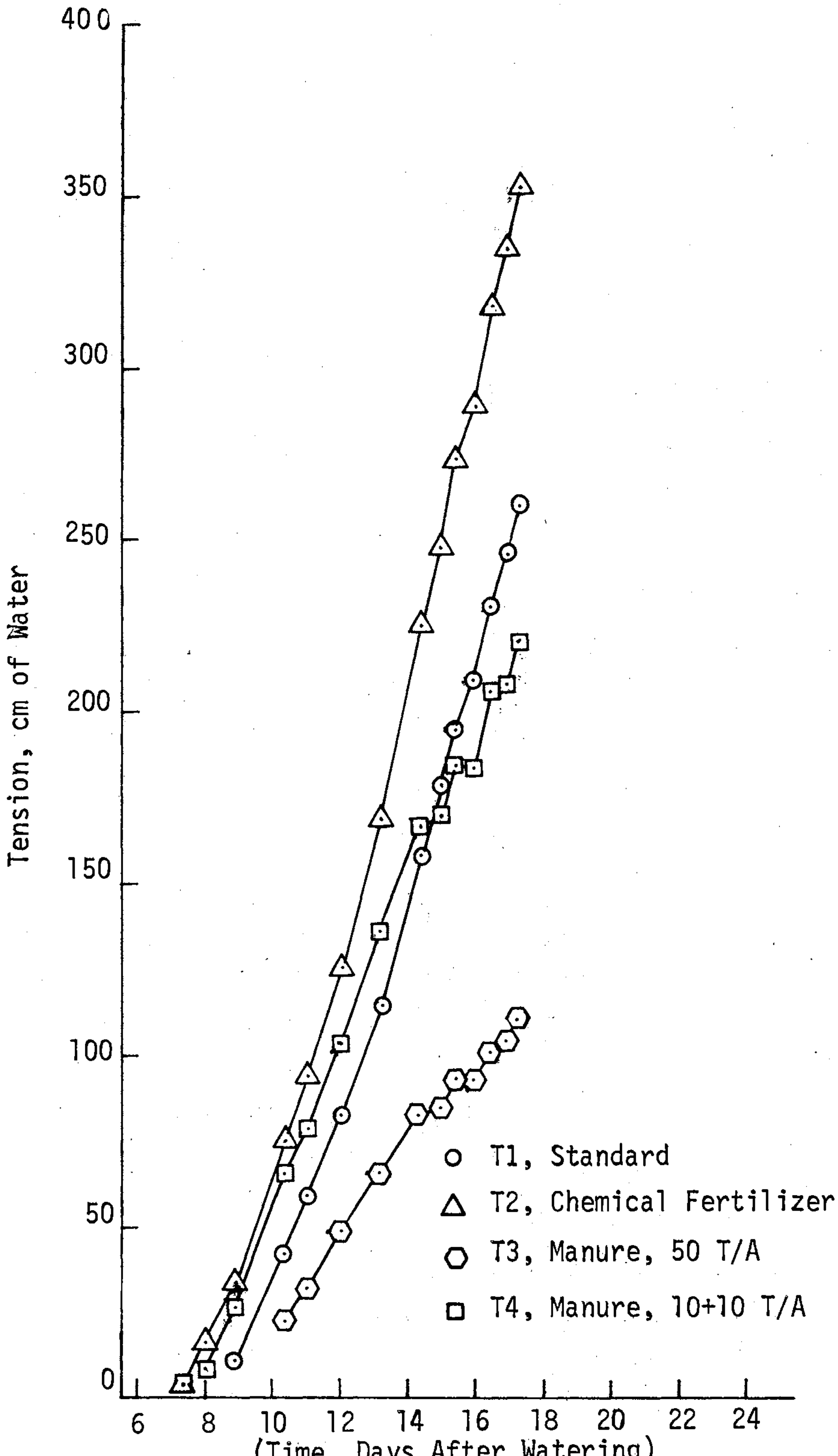


Figure 12D. Moisture Tension, Period IV, Level 1

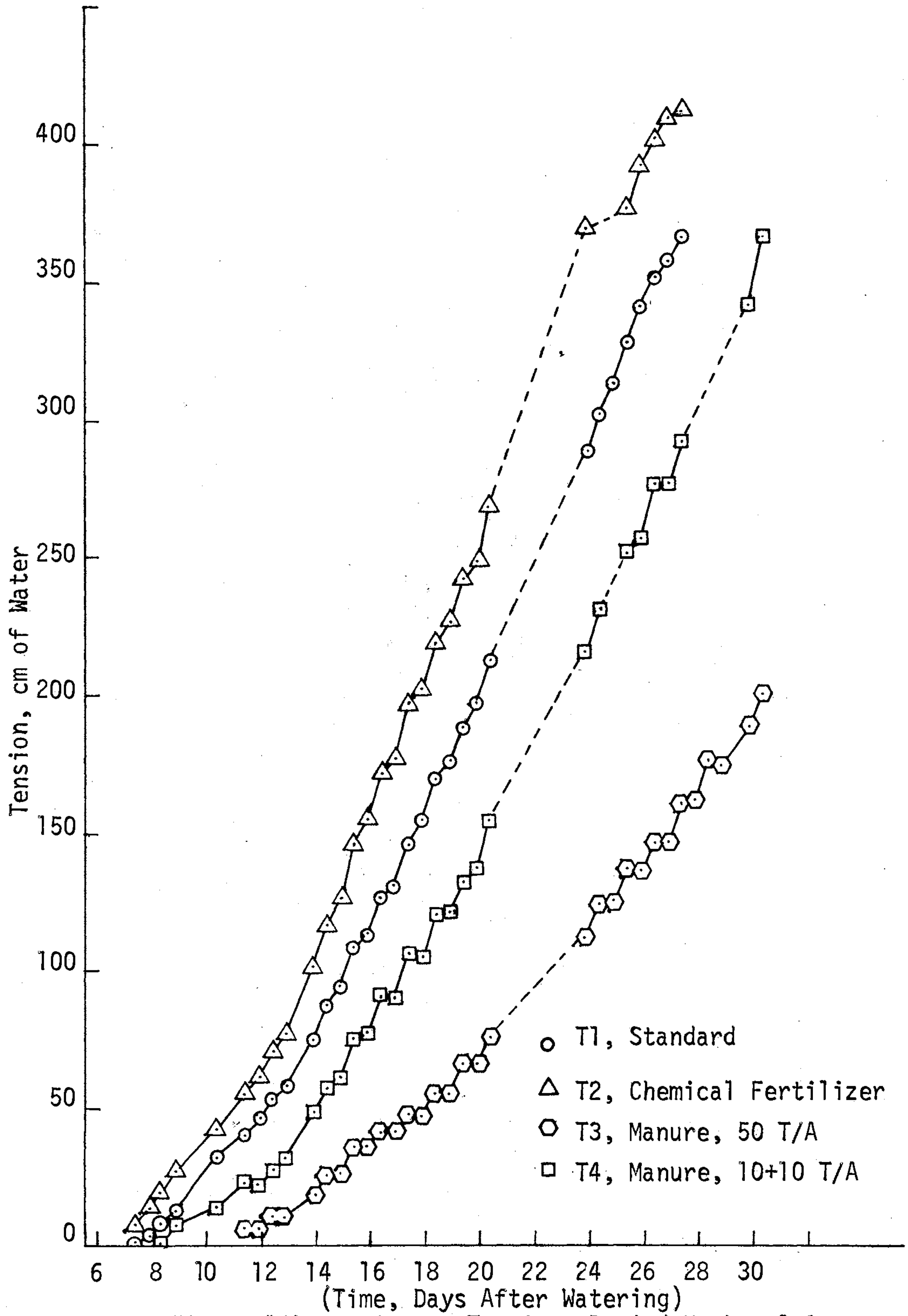


Figure 12E. Moisture Tension, Period V, Level 1

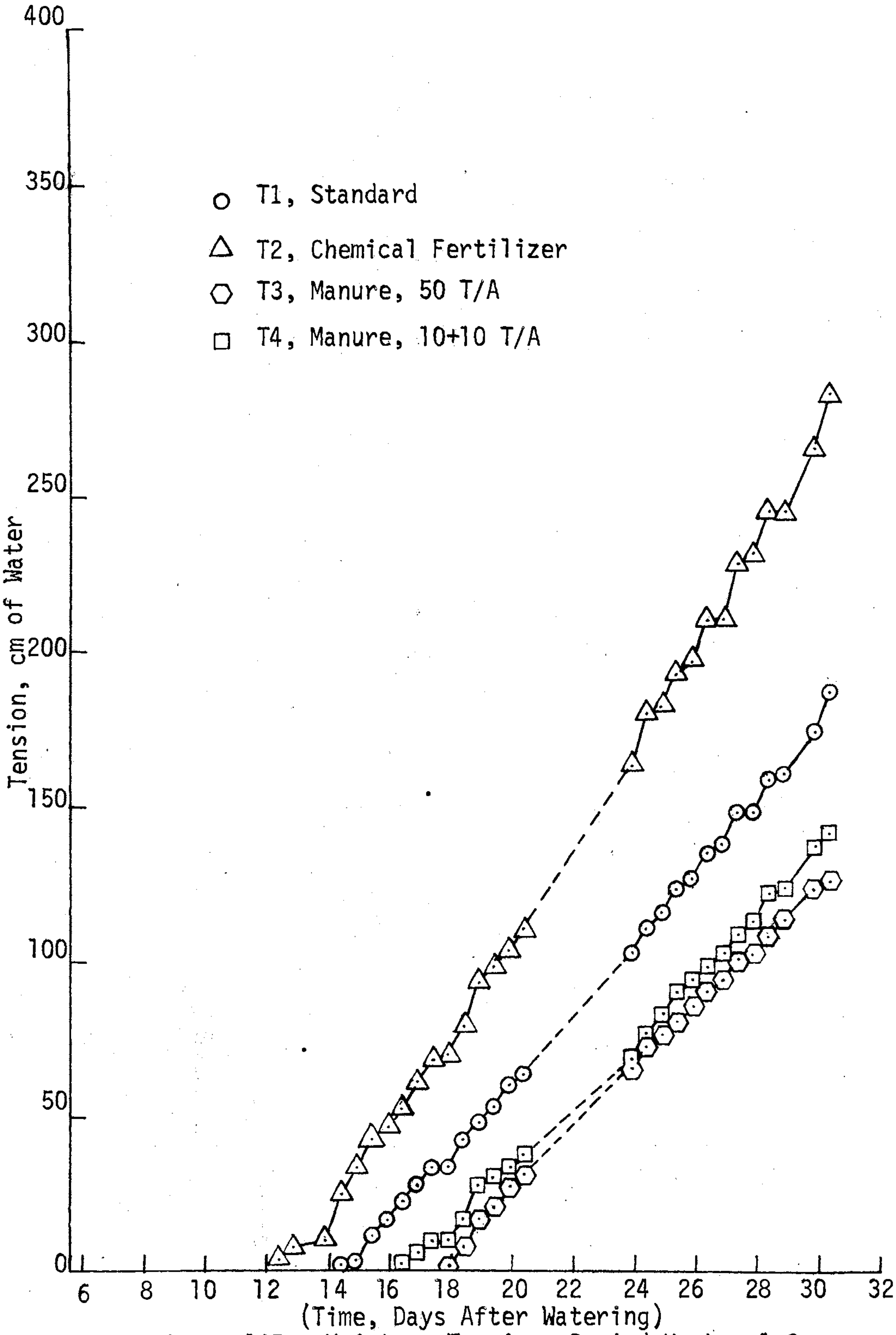


Figure 12F. Moisture Tension, Period V, Level 2

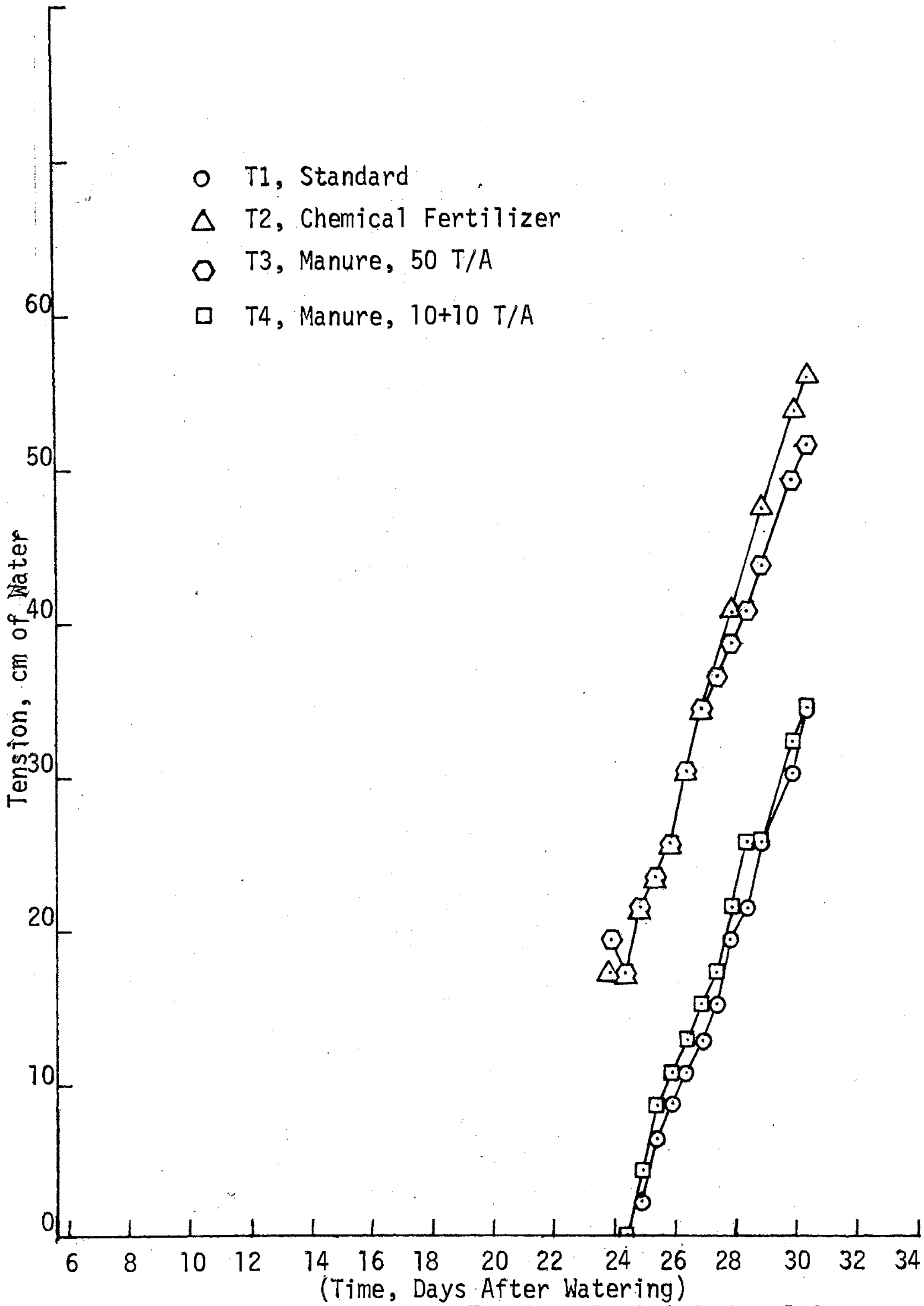


Figure 12G. Moisture Tension, Period V, Level 3

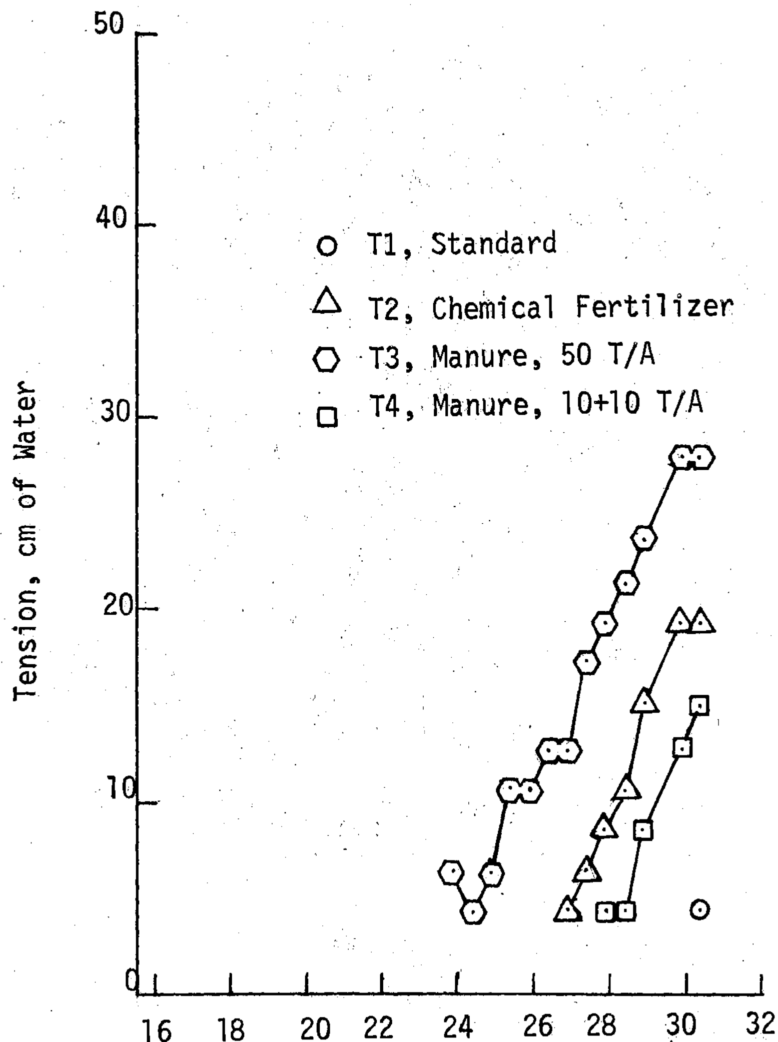


Figure 12H. Moisture Tension, Period V, Level 4

Note in Figures 12F, 12G, and 12H, that the relationship between the moisture tension at levels 2, 3, and 4 began to change. For instance, the T3 curve began to move up until at level 4, the tension in T3 was higher than all others and all three treated tanks had higher moisture tension than standard.

To correlate the moisture tension to actual moisture content, moisture release curves were developed. For comparison, the curves for levels 0 and 1 are shown in Figures 13A and 13B. Note that the shape of T3 is distinctly different at the surface where the manure was concentrated. This difference disappeared below level 1, and the shape of the moisture release curves was generally the same. There was a distinct difference in the shape of T4 at level 1, however. Note that at zero tension the moisture content in T4 was 23.5 percent or 1.5 percent higher than any other. This does not seem to correlate with tensiometer data for the same level. However, a plot of moisture content at field capacity for all tanks shows that T4 held more water at level 1 than all others.

Figure 14 shows that at the surface where manure was concentrated, moisture in T3 was 22.3 percent and T4 was 19.2 percent. The moisture content in T3 at field capacity at lower levels is shown to be generally lower than all other tanks. This phenomenon is verified by Figure 15, which is a plot of the moisture content versus depth of soil. The moisture differential in the four tanks from surface to level 4 is shown below:

Tank #	Moistures Differential
1	13.82%
2	13.03%
3	6.11%
4	11.35%

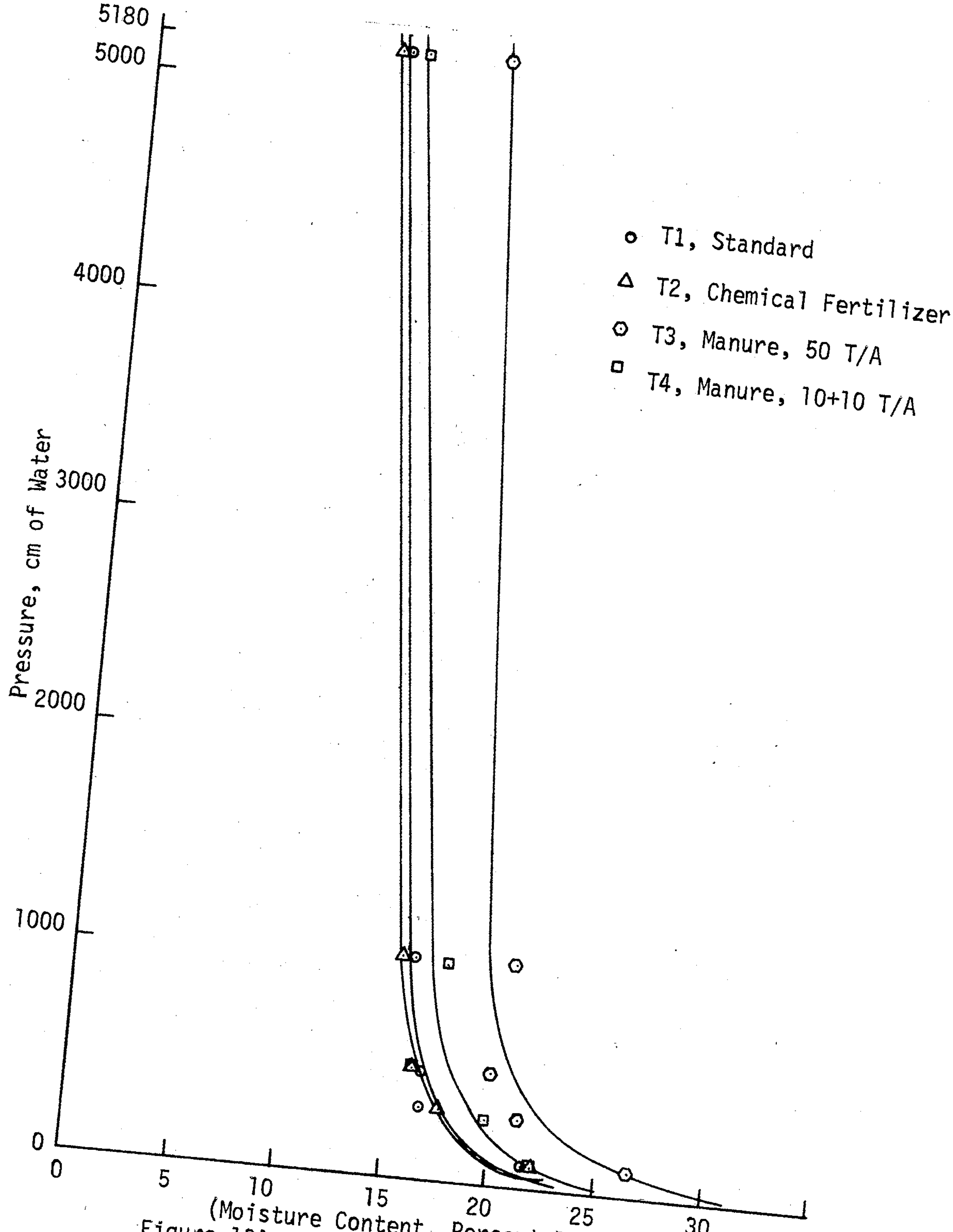


Figure 13A. Moisture Release Curve, Level 0

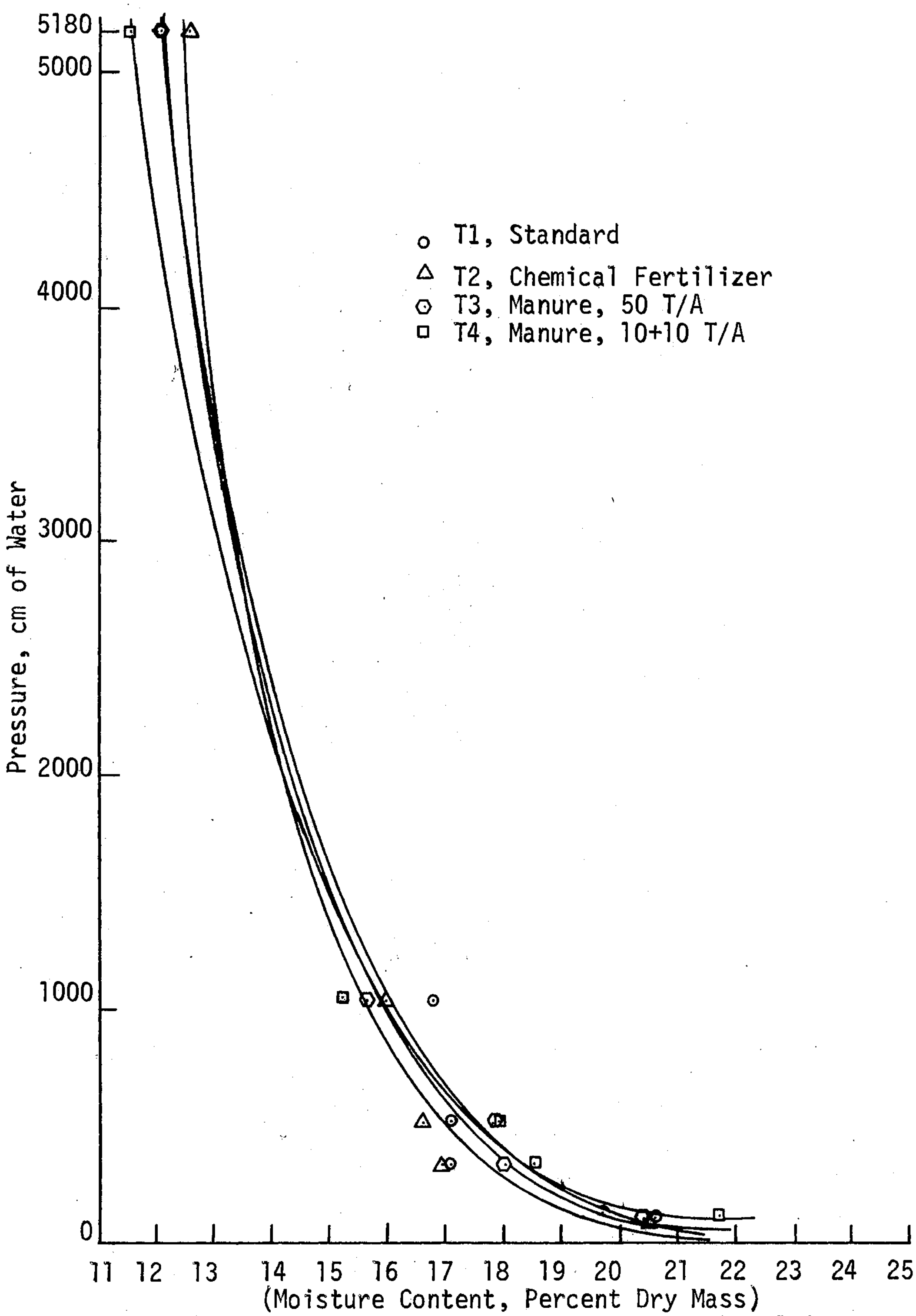


Figure 13B. Moisture Release Curve, Level 1

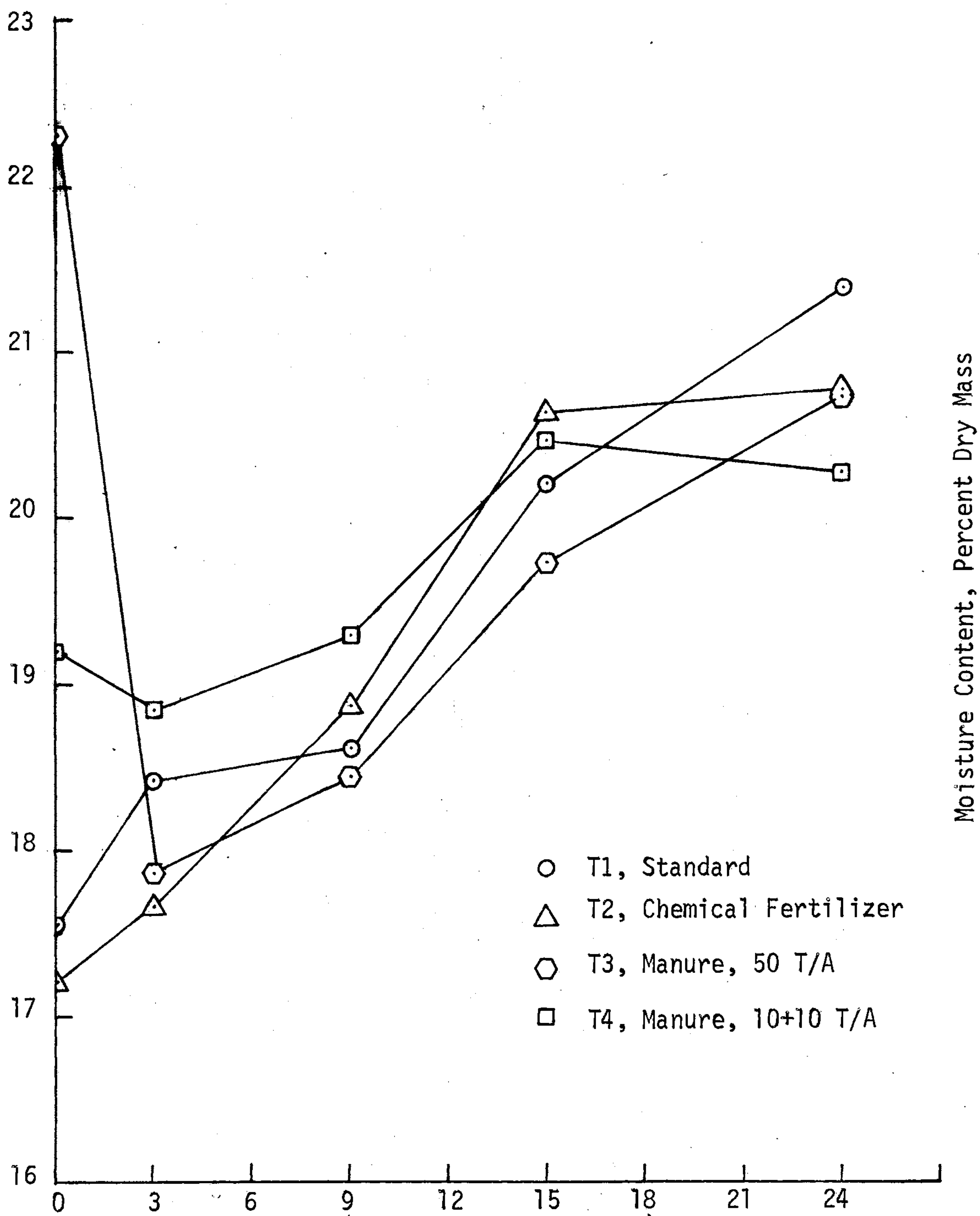


Figure 14. Moisture Content at Field Capacity

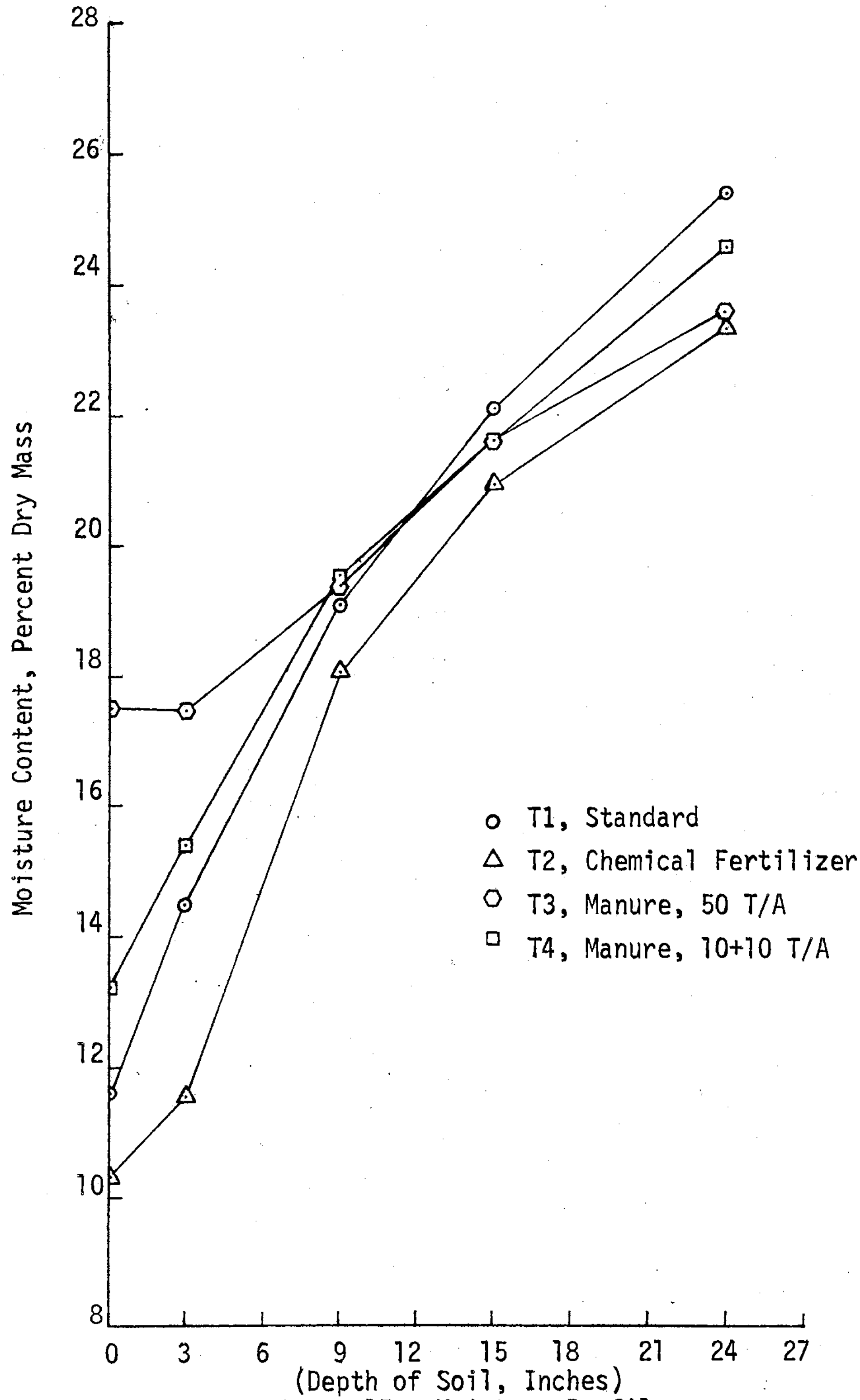


Figure 15. Moisture Profile

The moisture difference between the surface and level 4 in T3 is less than half the spread for T1 and T2.

The moisture tension at each tension reading was translated to actual moisture content using moisture release curves. The moisture content curves are plotted in Figure 16A through 16E for level 1 in all tanks. The same relationship exists between T1, T2, and T3, as occurred in the plots of moisture tension. The correlation between tension and moisture content is positive. Where the tension in T2 was three to four times that in T3, the moisture content was 2.3 percent to 3.3 percent less in T2 than in T3. This means that T2 had lost between 13.1 percent and 18.8 percent more moisture than T3.

The relationship between the moisture content in T4 and the other tanks was about the same as the moisture tension during periods I and II. However, during periods III, IV, and V, there was a distinct change in this relationship. The moisture content curve in T4 lies above the moisture content curve for T3 as seen in Figures 16C, 16D, and 16E. As shown in Figures 12C, 12D, and 12E, the corresponding moisture tension curves for T4 are generally between the curves for T1 and T3. Also note that the slope of the T4 content curve is greater than the others for period V and during the last part of the period the moisture content in T4 dropped below T3 and finally below T1.

Note the distinct steps in the T3 and T4 moisture content curves during period IV, and in the latter 2/3rds of period V. There was no moisture loss during the night and, in some instances, the moisture content seemed to increase at level 1 (at w+ 11 - 12 for T3 and w+ 17 - 18 for T4 during period V).

The moisture content at levels 2, 3, and 4 are compared during

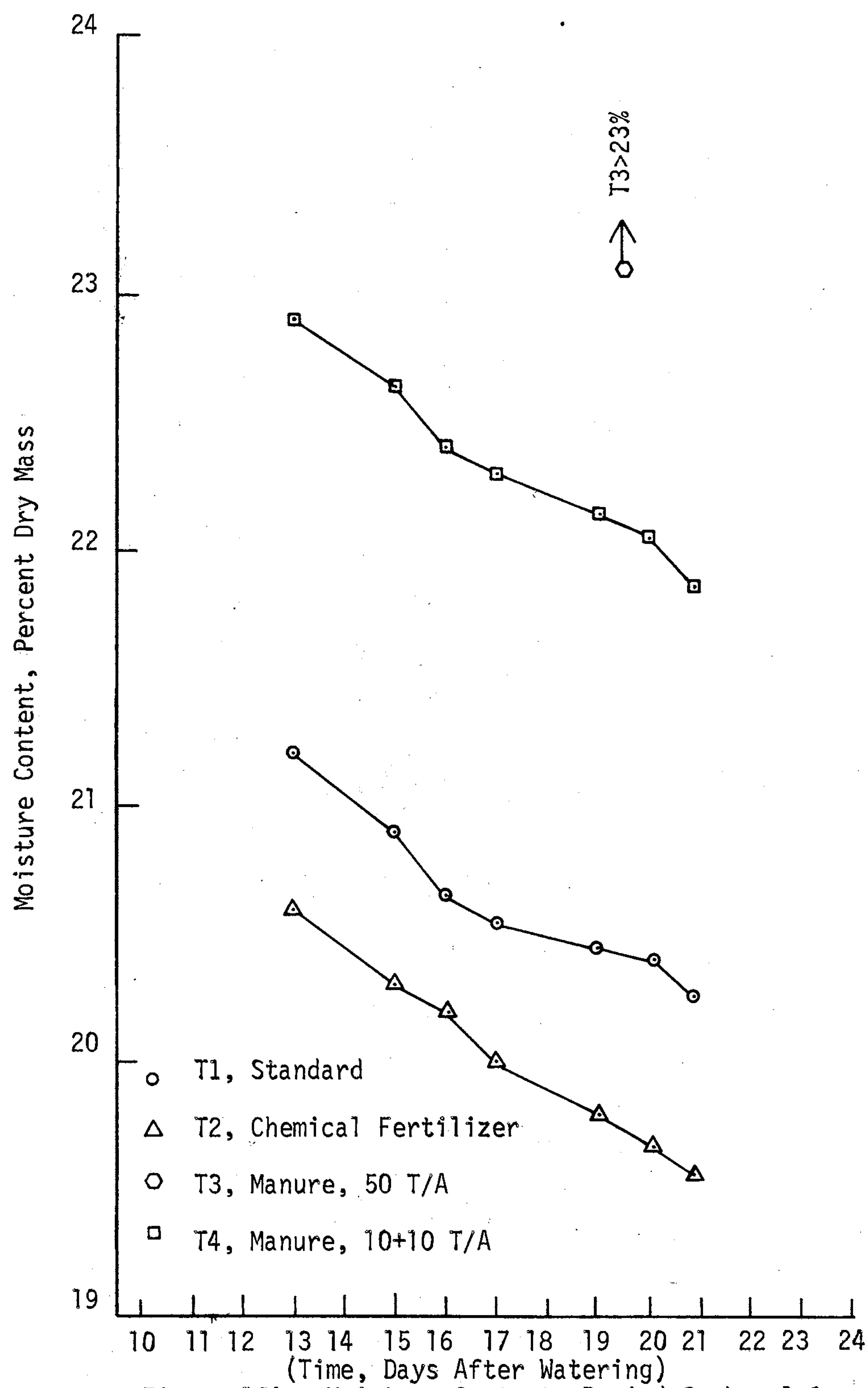


Figure 16A. Moisture Content, Period I, Level 1

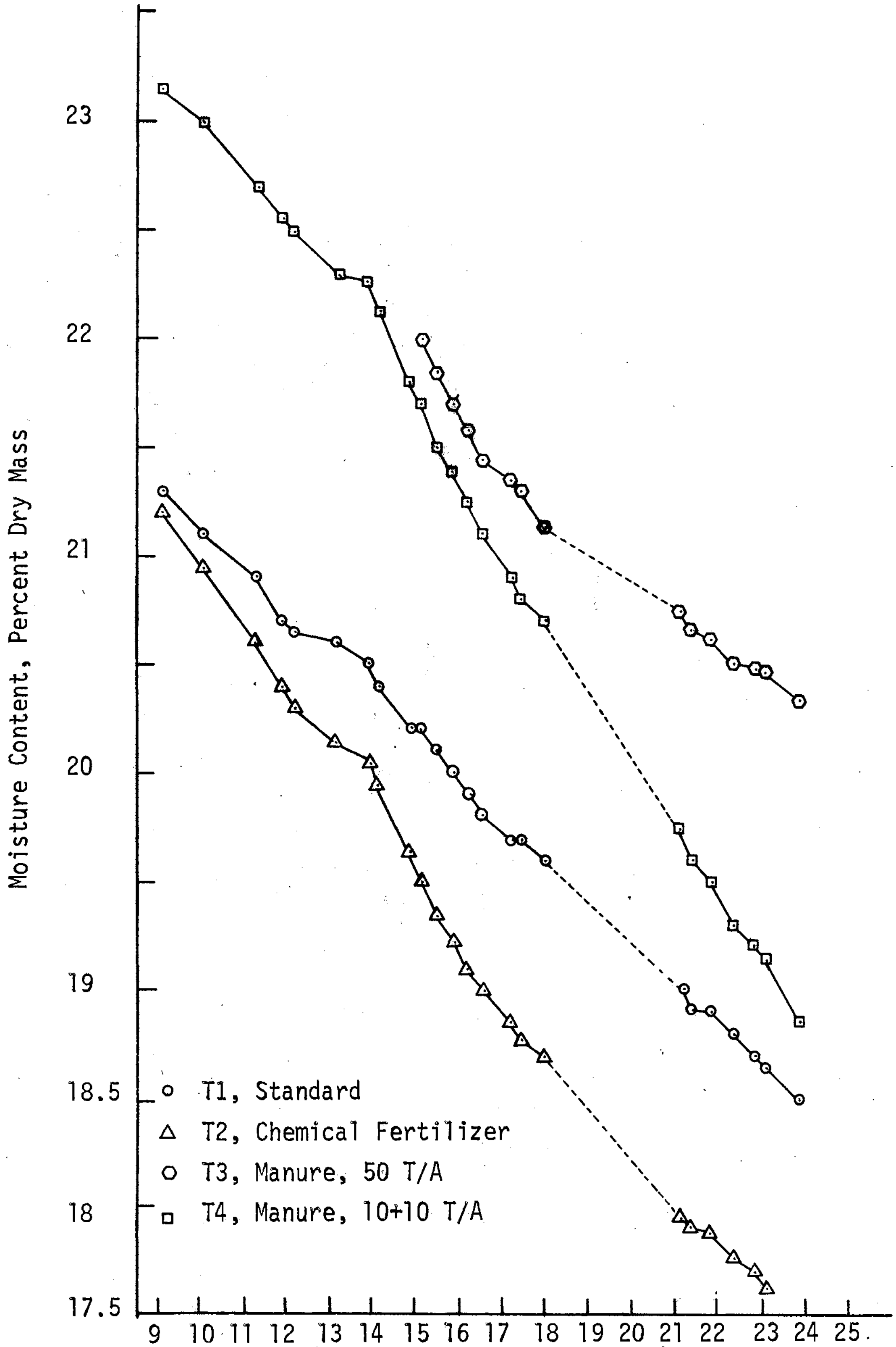


Figure 16B. Moisture Content, Period II, Level 1

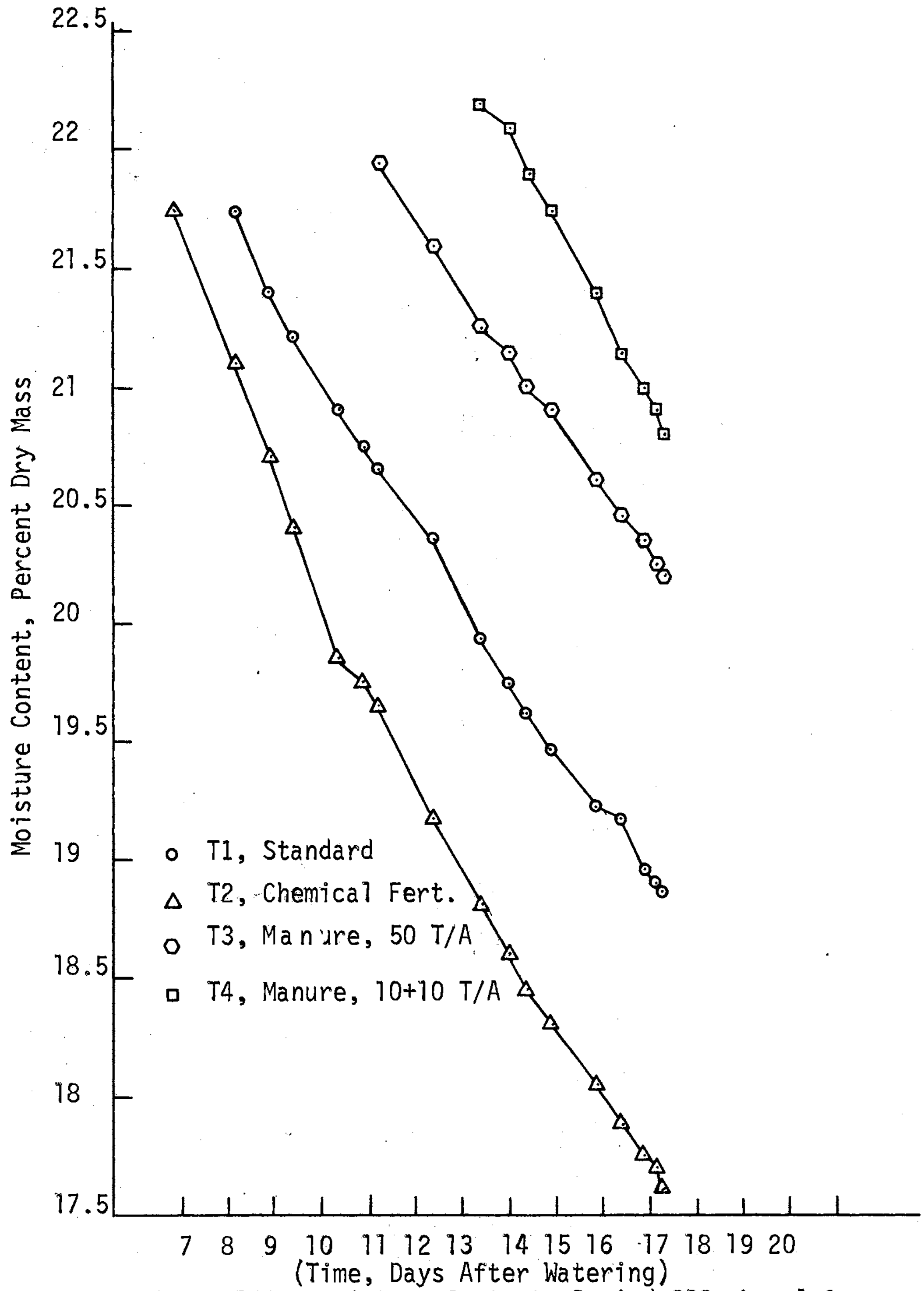


Figure 16C. Moisture Content, Period III, Level 1

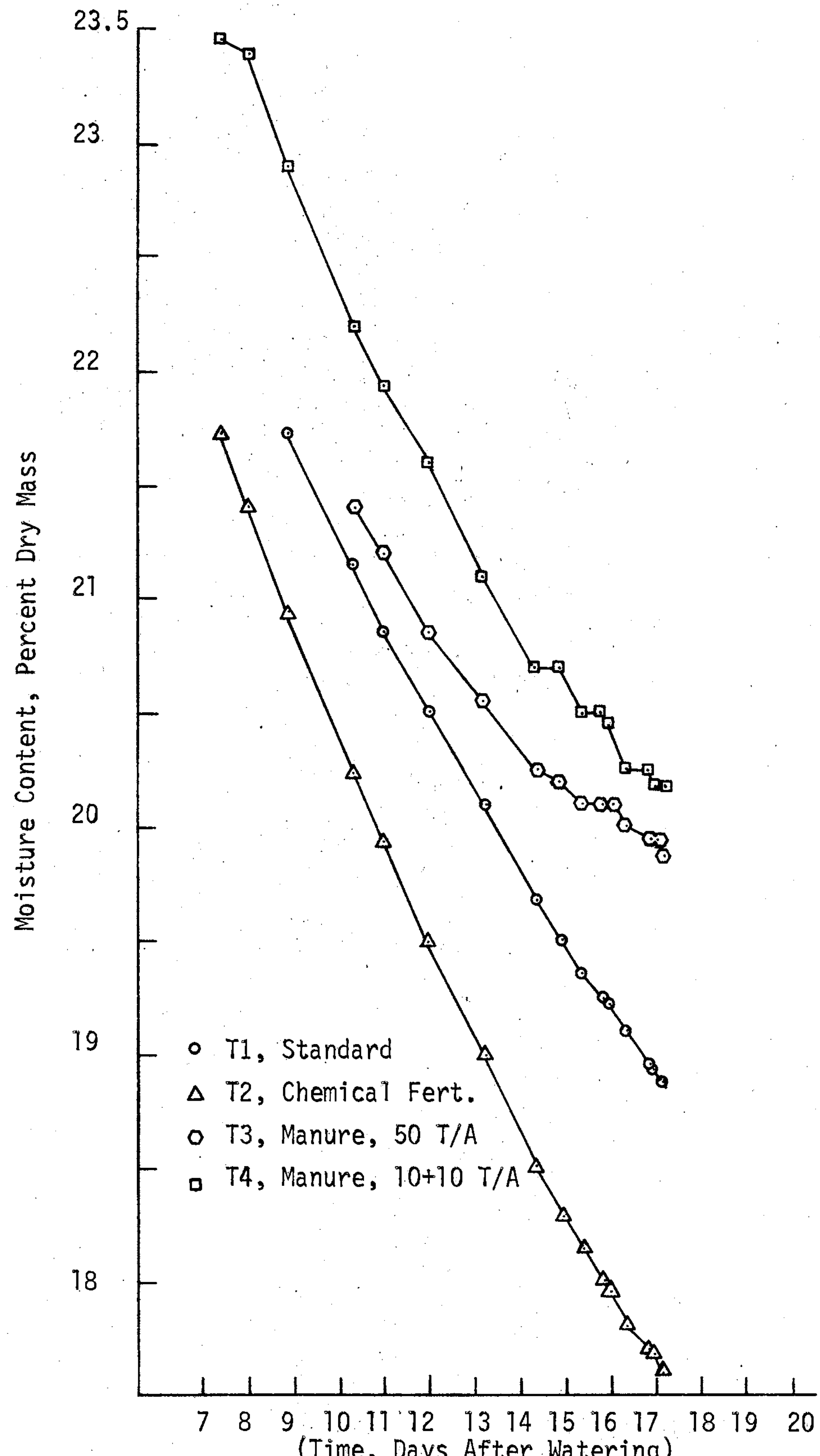


Figure 16D. Moisture Content, Period IV, Level 1

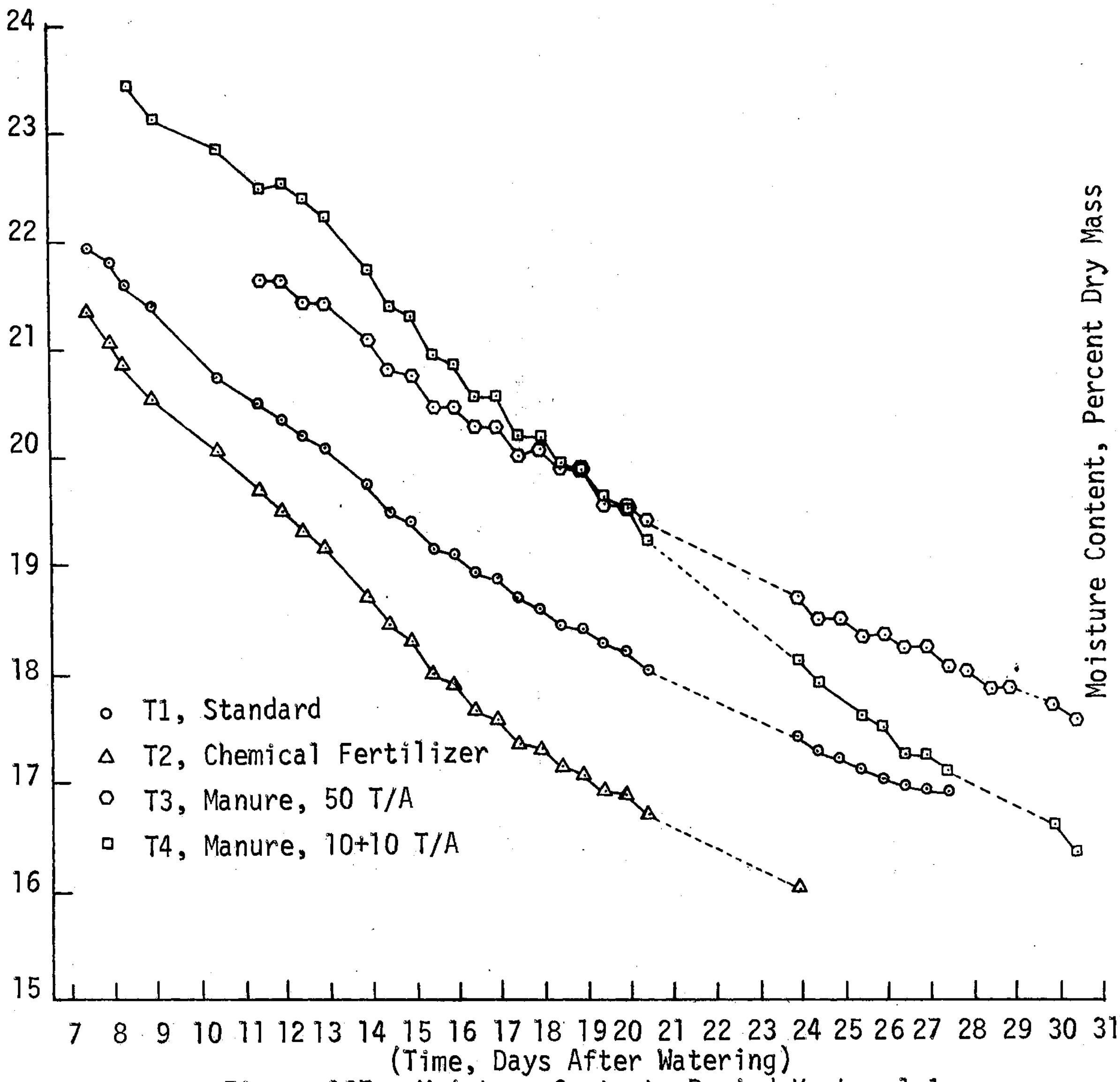


Figure 16E. Moisture Content, Period V, Level 1

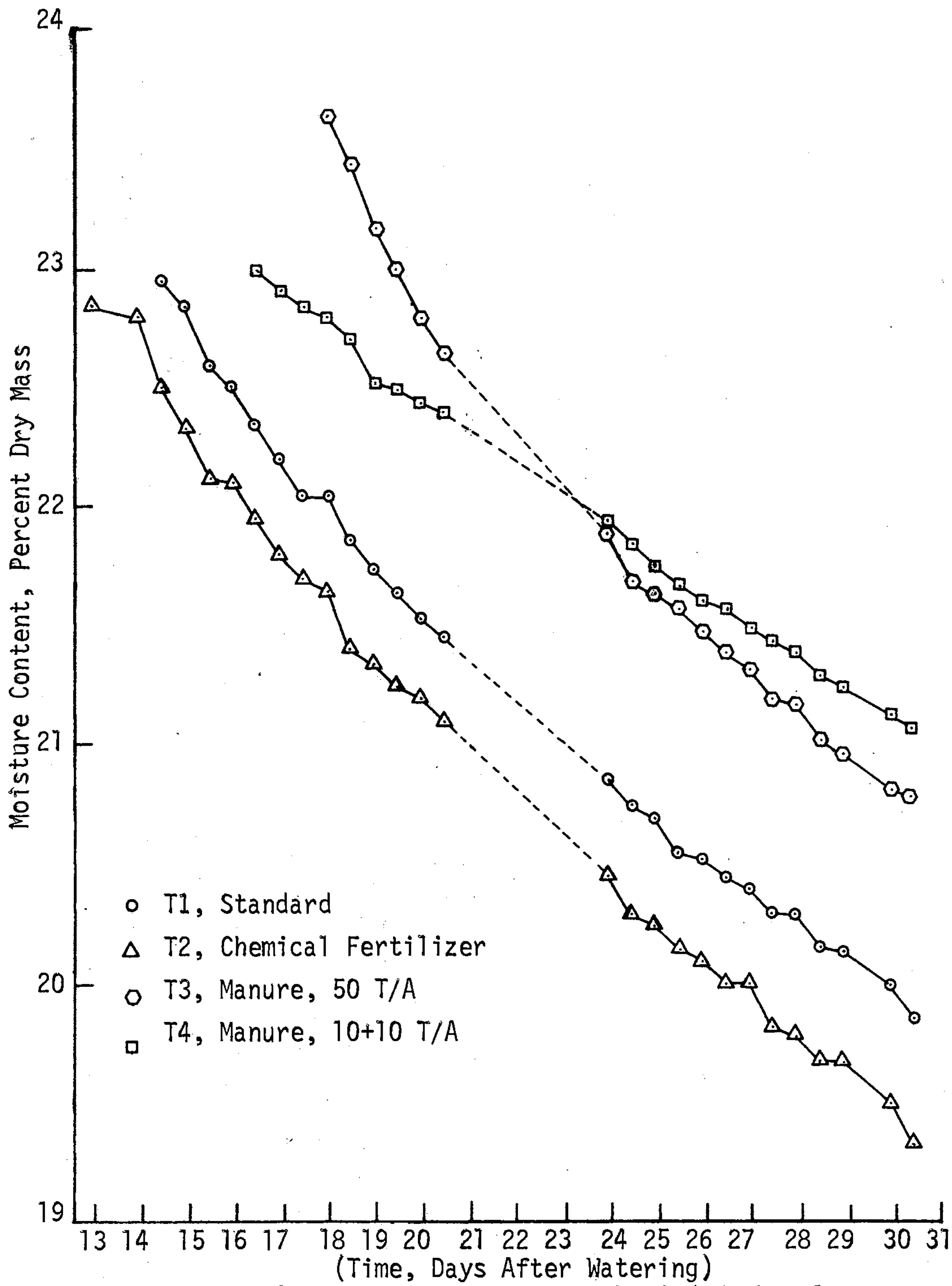
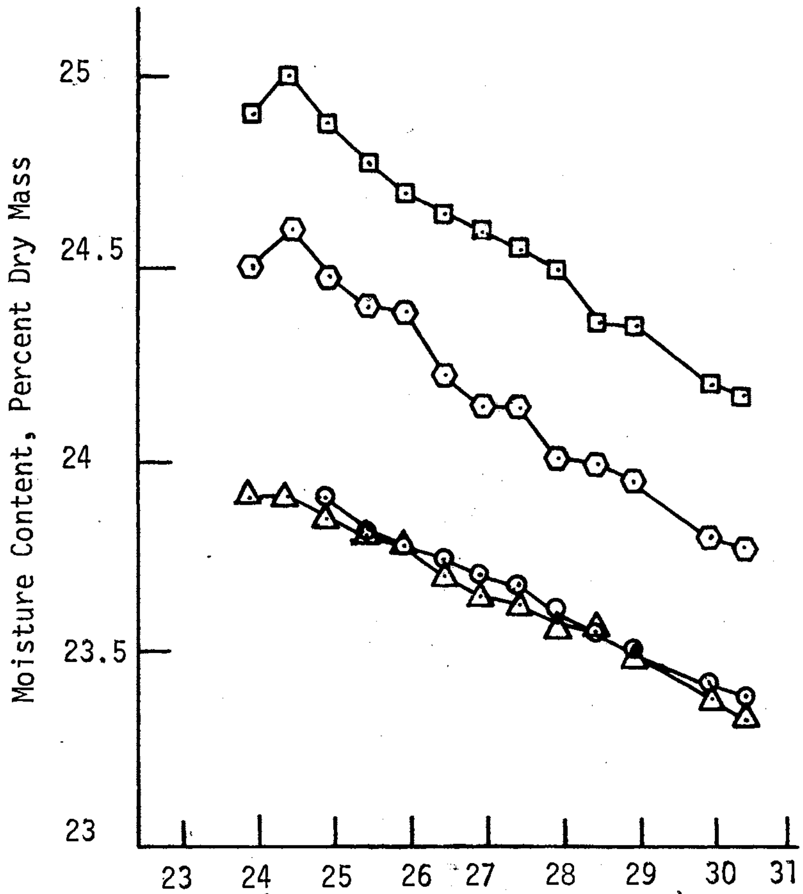


Figure 16F. Moisture Content, Period V, Level 2



(Time, Days After Watering)
Figure 16G. Moisture Content, Period V, Level 3

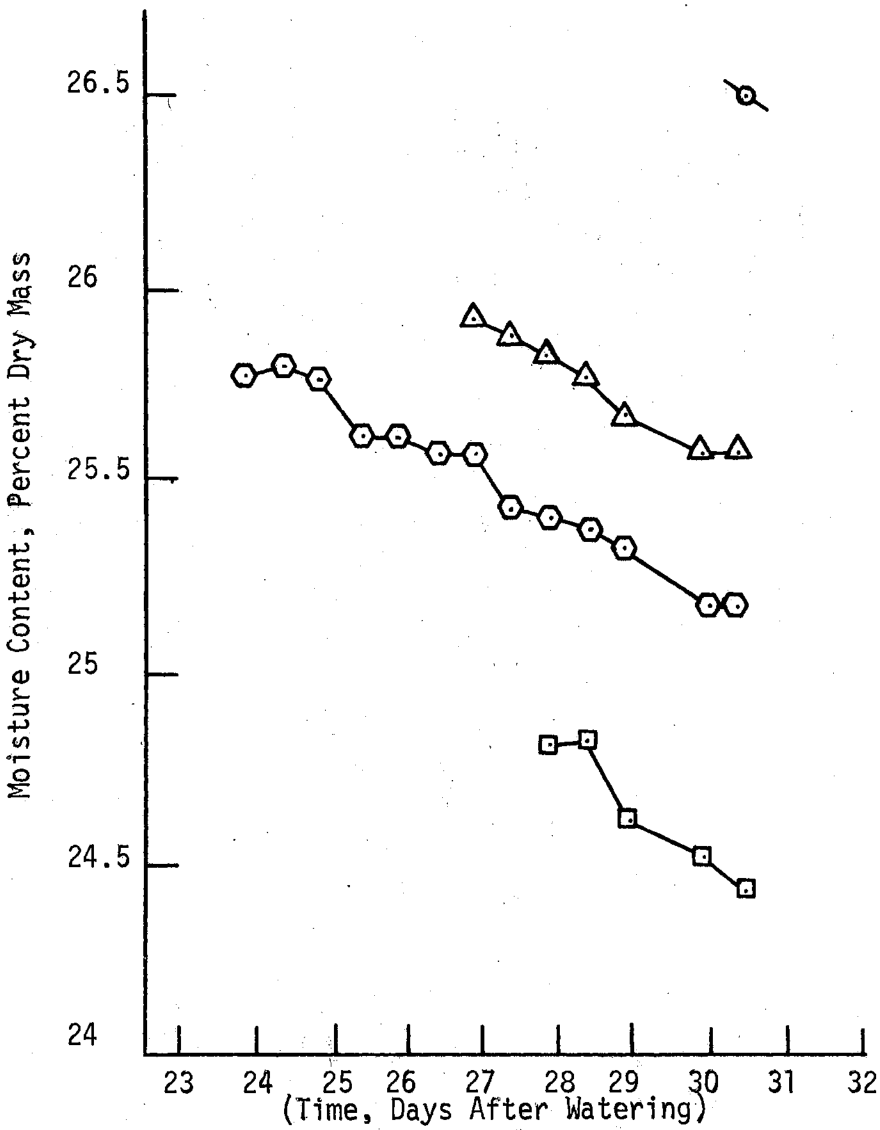


Figure 16H. Moisture Content, Period V, Level 4 period V only since this period was the only one that was long enough for significant movement at levels 3 and 4.

Note the change in relationship of the curves in Figures 16F, 16G, and 16H. The curves begin to shift position and by level 4 all treated tanks have less moisture than the standard, and T3 and T4 have less moisture than T2.

Again, note the erratic behavior of T4 as the content curve for T4 crossed over T3 at level 2, period V.

The bulk density determinations are listed below:

Level	T1	T2	T3	T4
0	1.23	1.27	1.05	1.26
1	1.23	1.22	1.27	1.18
2	1.22	1.22	1.27	1.27
3	1.20	1.19	1.24	1.24
4	1.32	1.33	1.28	1.26

The most significant change was in the decrease in bulk density in T3 at the surface to 1.05 or a decrease of 14.6 percent from standard. Another difference occurred at level 4 in T1 and T2, where the bulk density increased to 1.32 and 1.33, respectively, after it had decreased gradually with depth.

B. Chemical Analyses

1. Nitrate

The nitrate concentration as measured in the water extracted increased in all tanks at all levels during the first 100 days after the treatment was added. As shown by Figures 17A through 17D at level 1, T4 had the most rapid initial increase with T3 beginning a very sharp increase at T+65 and increasing to 1200 mg/l by T+82 and again at T+100. Sharp decreases generally occurred in all tanks immediately

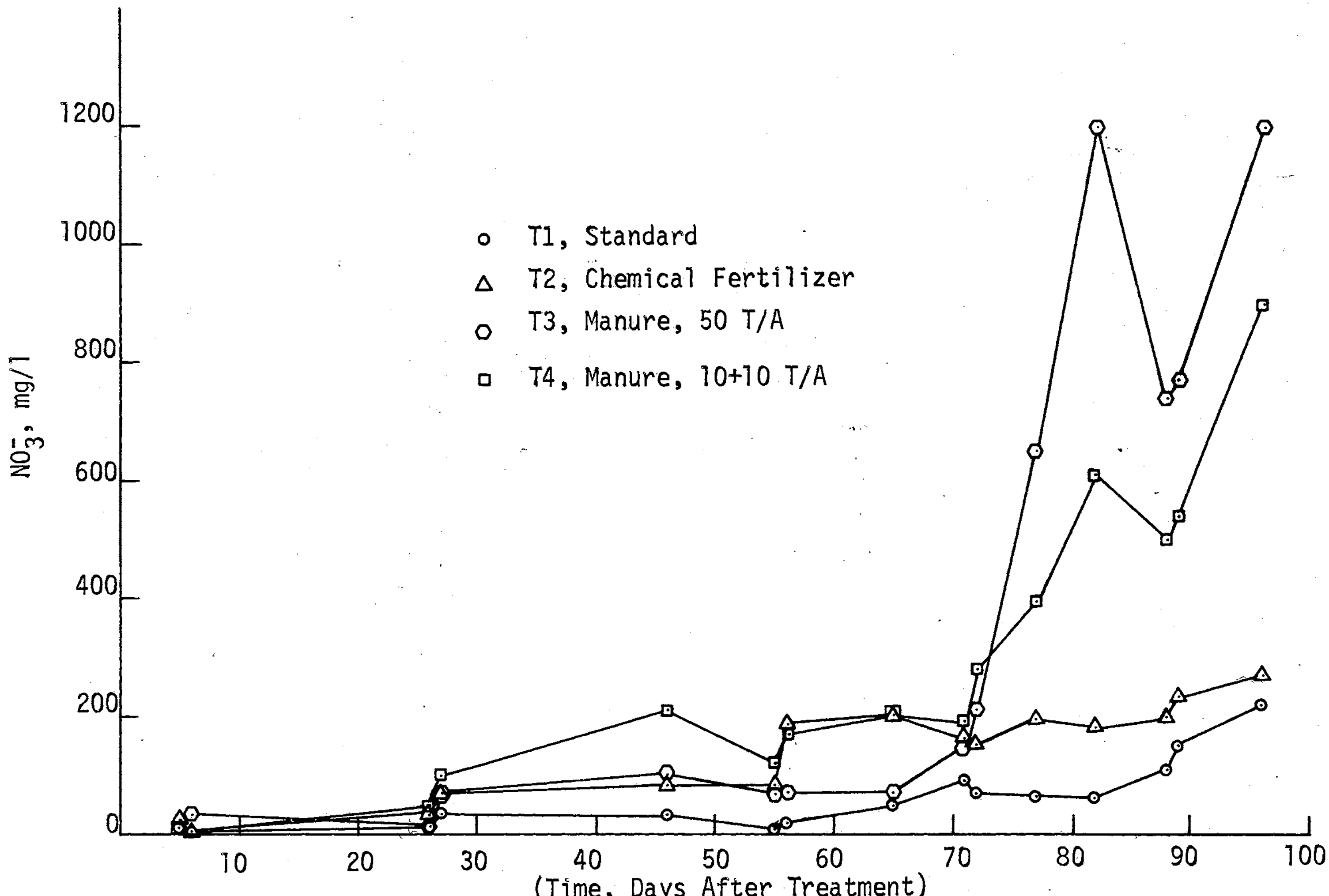


Figure 17A. Nitrate Concentration, Level 1

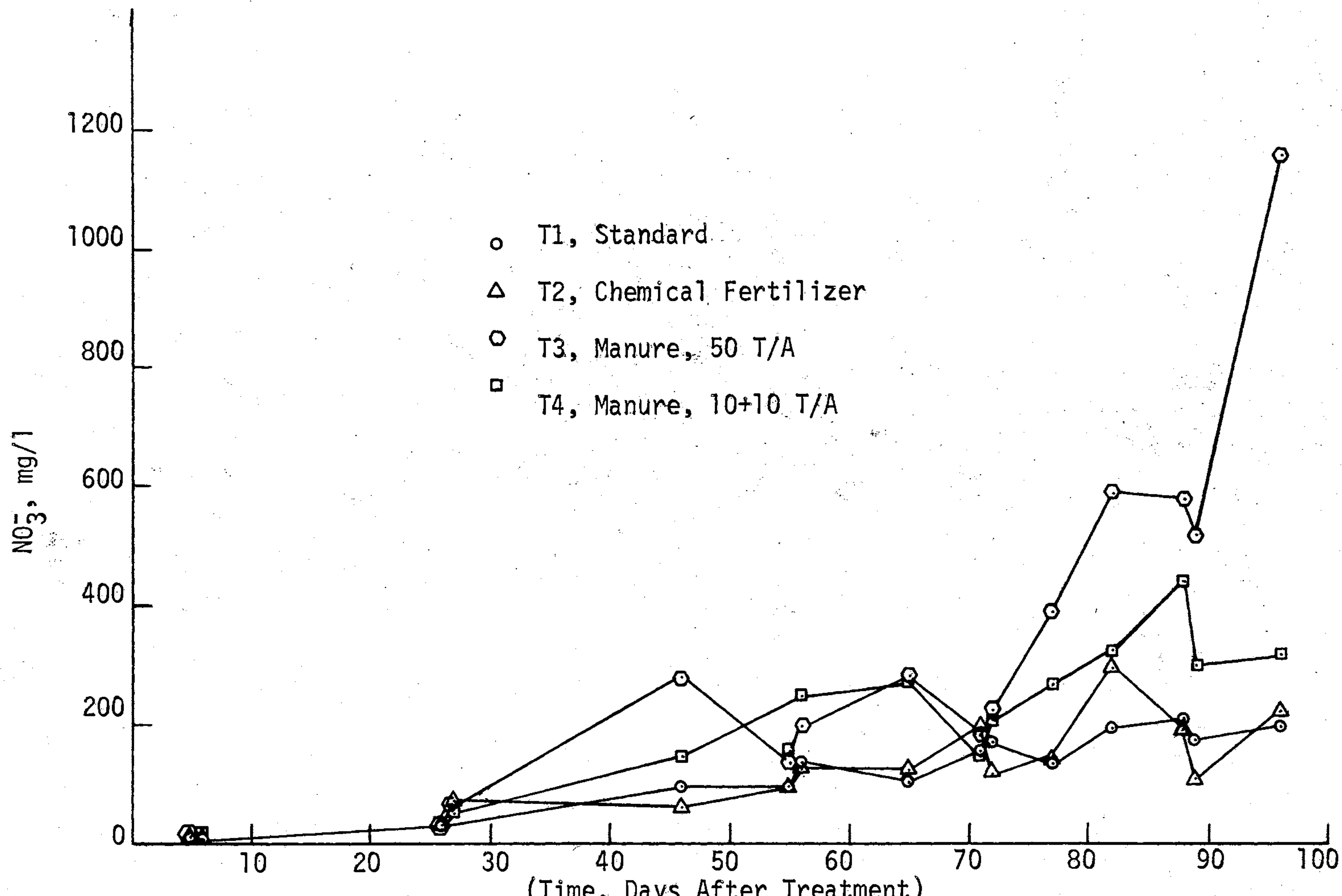


Figure 17B. Nitrate Concentration, Level 2

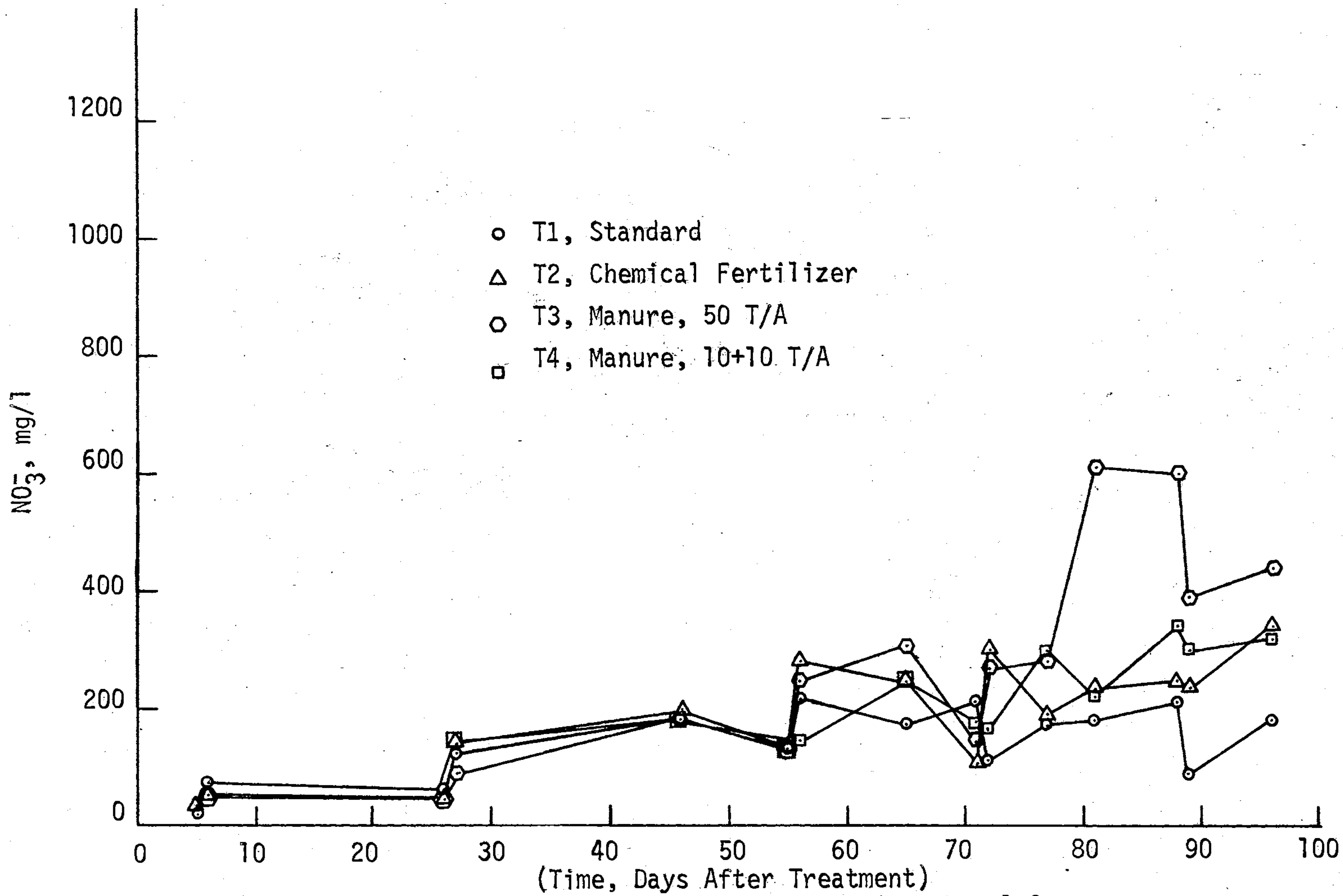


Figure 17C. Nitrate Concentration, Level 3

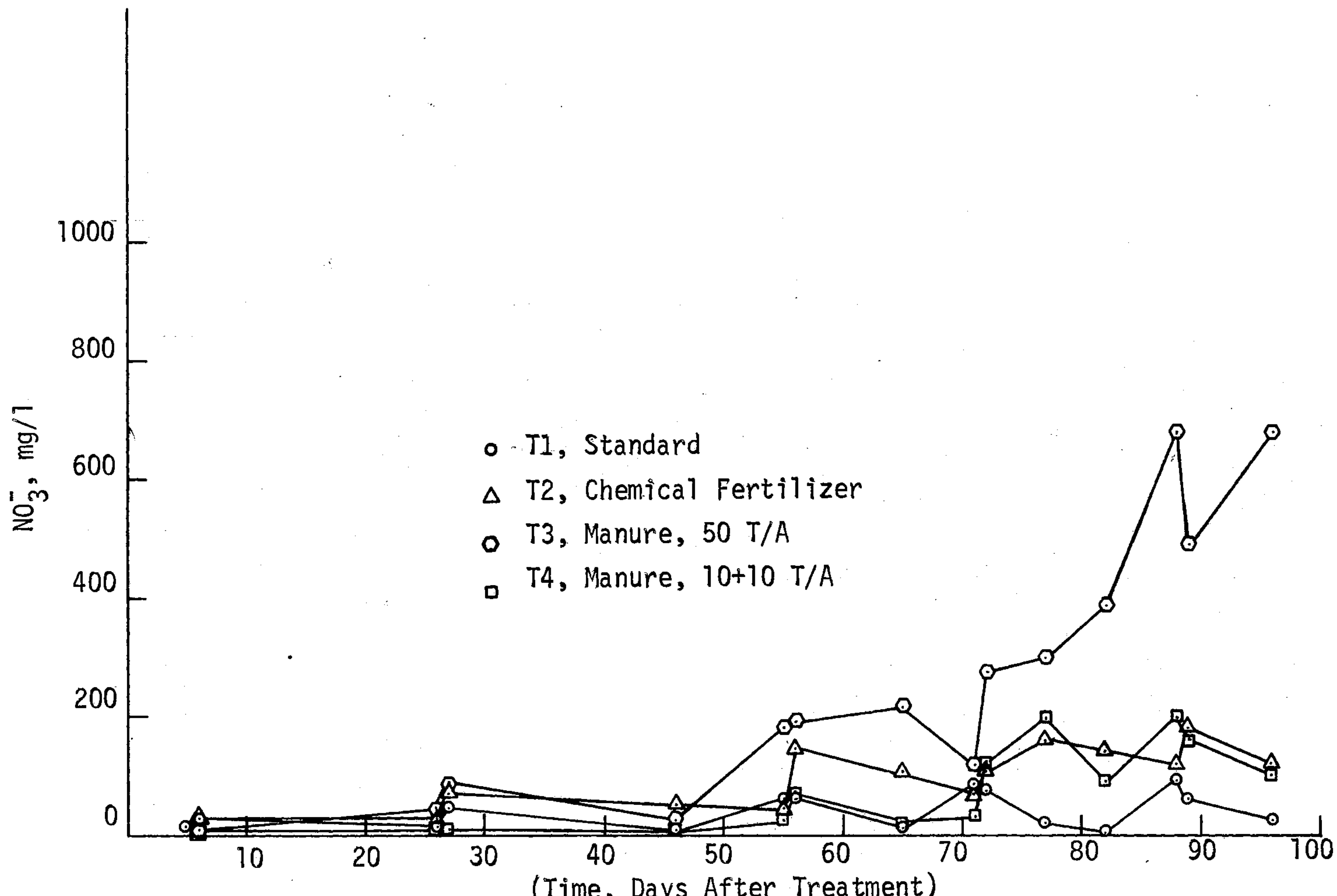


Figure 17D. Nitrate Concentration, Level 4 following watering. T4 concentration reached 900 mg/l, T2 reached 270 mg/l, and T1, the standard with no additives, reached 220 mg/l at T+100 days. Correcting all readings for standard by subtracting the level in T1 or standard, the NO_3^- concentrations apparently caused by the treatment were:

Tank	NO_3^- Concentration (mg/l)	STD %
T1	-	100
T2	50	123
T3	1080	500
T4	780	350

The NO_3^- concentration in the tap water was checked and found to be less than one mg/l.

The nitrate concentration at level 2, Figure 17B, increased with T1 and T2 having similar patterns and approximately the same increase. T3 and T4 showed significant increases beginning at T+70 days and reaching 940 and 120 mg/l, respectively, after the standard value was subtracted.

The nitrate concentration (mg/l) at levels 3 and 4 corrected for standard at T+100 was:

	level 3	level 4
T2:	160	95
T3:	260	655
T4:	140	75

Note for levels 3 and 4, the NO_3^- concentration for T2 and T4 were nearly identical, and only slightly above the standard. However, the high concentrations in T3 infiltrated to the 3 and 4 level with only 50 percent being absorbed by soil or plant. In the case of T3 and T4, the tanks treated with cow manure, it was 60 to 70 days before free NO_3^- began to be detected in the water. The high buildup at levels 3 and 4 were simultaneous with levels 1 and 2, beginning about 60 days after manure was put in the tanks.

2. Ammonia

Significant levels of ammonia appeared only in the tanks receiving the manure, T3 and T4. Figure 18 shows the buildup and decline of ammonia at level 1, where the manure was concentrated. The NH_3^+ concentration reached a maximum of 10 mg/l in T3 at T+26 days, and gradually decreased to a trace by T+55. Note that this disappearance corresponds to the beginning of the buildup of the NO_3^- concentration in T3.

The level of ammonia in T4 reached 1.5 mg/l at T+45 days, and rapidly decreased to a trace ty T+55. At levels 2, 3, and 4, the amounts of ammonia detected were normally traces. However, 7.5 mg/l were measured in T3, level 2 at T+46. This had decreased to a trace by T+55.

3. Soil Analyses

Table XI is the soil test report of the soil before and after the study.

a. pH.

No essential difference.

b. Organic Matter

Only the heavy manure in T3 caused an increase in organic matter from 1.4 percent to 2.8 percent.

c. Phosphorous (P)

The P concentration increased in all treated tanks. The increase was only at the surface in all cases. Below nine inches, the P

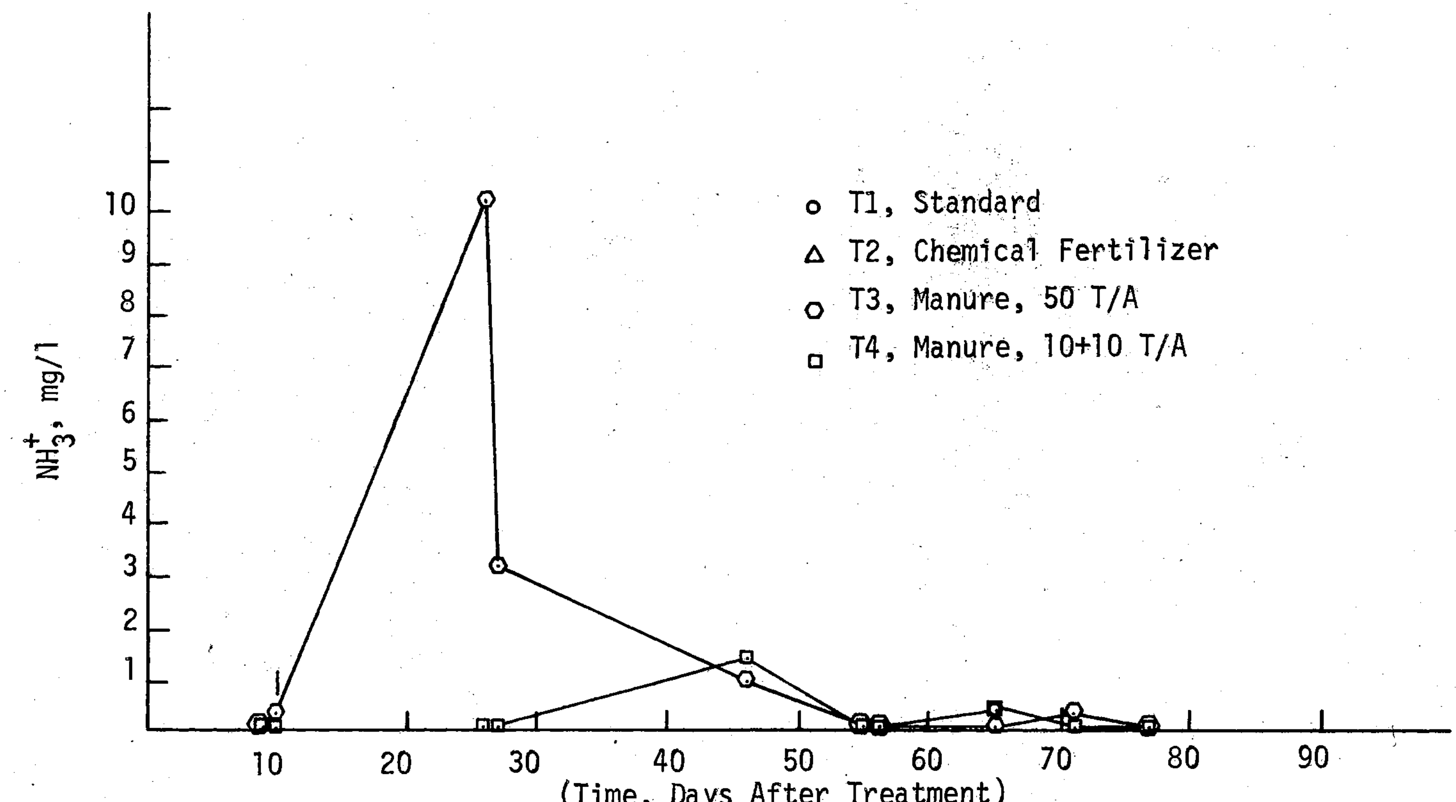


Figure 18. Ammonia Concentration, Level 1

concentration in all tanks was actually lower than the original soil.

d. Potassium (K)

The soil had tested high in K, therefore none was added to T2 as reflected here. Note the significant increase in K from the application of manure in T3 and T4.

e. Calcium

A very small difference occurred between the tanks. However, T3 and T4 tested some higher, indicating some buildup from the manure.

f. Magnesium

Approximately a 20 percent increase in magnesium occurred in the tanks receiving manure.

g. Iron

Iron level increased 22 percent in T2 where none was added. Iron increased in T3 and T4 at the rate of 17 percent and 8 percent, respectively.

h. Zinc

The zinc level decreased sharply in all tanks, but less in T3 and T4, which had received the manure.

i. Manganese

Manganese decreased slightly in all tanks except level 1 and level 4 of T4, where it was the same at level 1, and increased at level 4. The manganese profile in the tanks was:

T1, increased with depth
T2, decreased with depth
T3, decreased at nine inches, then increased at 24 inches
T4, decreased at nine inches, then increased at 24 inches.

TABLE XI

SOIL TEST REPORT

State Lab. #	Senders Sample #	Soil Reaction B.I.	Soil Reaction pH	% OM	Lbs/A P	Lbs/A K	Lbs/A Ca	Lbs/A Mg	PPM Fe	PPM Zn	PPM Mn	PPM B	Lbs/A NO_3-N* Sur.	CEC (meq/100 gm)
5815	0/ 0	6.8	6.1	1.4	10	225	2,120	750	23.2	15.2	10.9	.2	<10	11.6
5816	1/ 0	6.8	6.3	1.4	10	230	2,230	860	20.2	1.8	7.6	.3	19	12.4
5817	1/ 9	6.8	5.8	1.3	2	180	1,750	740	21.8	1.2	8.4	.3	19	11.5
5818	1/24	6.8	5.8	1.2	5	170	1,980	820	25.0	1.2	9.8	1.6	21	12.4
5819	2/ 0	6.8	5.6	1.4	143	190	1,920	760	28.0	1.8	9.5	.4	28	12.2
5820	2/ 9	6.7	5.7	1.4	5	190	2,000	820	23.0	1.0	9.2	.3	22	11.6
5821	2/24	6.8	5.7	1.3	5	165	1,870	770	22.8	1.0	9.0	.9	20	11.6
5822	3/ 0	6.8	5.9	2.8	655	1,210	2,400	920	27.5	3.0	9.4	.1	350	13.7
5823	3/ 9	6.8	5.6	1.3	5	235	2,010	820	22.0	1.1	8.0	.3	42	11.6
5824	3/24	6.8	5.6	1.3	7	165	2,020	800	27.5	.9	10.8	1.9	51	12.3
5825	4/ 0	6.8	5.9	1.4	121	525	2,300	930	25.0	2.1	10.9	.3	120	13.3
5826	4/ 9	6.8	5.7	1.2	7	260	1,930	840	23.5	1.2	10.4	.2	25	11.3
5827	4/24	6.8	5.7	1.2	5	165	2,010	810	26.0	1.3	11.2	2.2	30	14.6

*Lbs. N per every six inches samples.

j. Boron

Boron content generally increased in all tanks, but note the increase in concentrations at the bottom of the tanks, which was nearly an order of magnitude in T3 and T4, eight times in T1, and 4.5 times in T2.

k. Nitrate-Nitrogen

Nitrate increased in all tanks compared to the original soil. Note the great increase in NO_3^- at level 1:

Tank	NO_3^- Concentration (mg/l)	Percent STD
T1	19	100
T2	28	147
T3	350	1840
T4	120	630

These values correlate with the NO_3^- concentrations detected in the water and discussed in Sec. 1 above. The nitrate concentration in the soil at lower levels as determined from soil analyses are considerably lower in T3 and T4 with respect to the amount at the top of the tank than that detected in the water at the lower levels. However, there is some buildup, since T3 at level 4 was 243 percent of standard, while T2 was essentiallly the same as standard.

l. Cation Exchange Capacity (CEC)

Compared to standard, the CEC at level 1 decreased 1.2 percent in T2, increased 10.5 percent in T3, and increased 9 percent in T4. At other levels, the CEC was essentially the same except in T4 at level 4, where it increased 17.7 percent over standard.

4. Chemical Oxygen Demand (COD)

a. COD of Manure

The COD of the raw manure was measured to be 58,850 mg/l.

b. COD of Effluent

The average COD of the free water (effluent) at the bottom of the tanks was measured to be:

Tank	COD (mg/l)
T1	13.3
T2	13.3
T3	13.0
T4	63.3*

(*This value seemed uncommonly high; it was more likely to have been in the neighborood of 26.7 percent.)

The soluble COD at level 4 was measured to be:

Tank	COD (mg/l)
T1	12.9
T2	6.3
T3	9.3
T4	7.0

C. Plant Growth

1. Plant Height and Weight

The height above the surface of the tallest sprig of grass was recorded and plotted. This growth is shown in Figures 19A through 19D. U-3 Bermuda grass was sprigged into each tank at the beginning of period II.

Note the slow growth rate of the grass in T3 during period II, as shown in Figure 19A. The grass was cut after a 26-day period. The yield is compared below:

Tank	Dry Matter (gm)	Percent Dry Wt.	Percent STD
T1	2.62	18.0	100
T2	4.21	17.3	161
T3	2.02	19.6	77
T4	4.07	18.1	155

Figure 19B shows the growth during period III. Note the pattern of growth change. The grass in T3 crossed over T2 at T+65, i.e., 65 days after the tanks were treated with nutrients. The grass in T4 showed less height growth during this period than did T1. The yield comparison is as follows:

Tank	Dry Matter (gm)	Percent Dry Wt.	Percent STD
T1	2.05	18.6	100
T2	1.88	18.6	91.7
T3	1.85	19.6	90.3
T4	1.95	18.4	95.2

Figure 19C shows height during period IV. Note that the height of the grass in T3 and T4 was above standard in both cases, with T2 below standard, seven days after the beginning of this period. A comparison of yield data for this period is shown below:

Tank	Dry Matter (gm)	Percent Dry Wt.	Percent STD
T1	1.48	19.0	100
T2	1.56	19.5	105.2
T3	1.60	19.7	108
T4	1.72	17.8	116

Figure 19D shows height during period V under drought conditions. T3 sustained higher growth throughout this period. The grass in T2 was taller than standard, but in T4 it showed a period of no growth from 18 to 26 days after this period began. A comparison of yield data during this period is as follows:

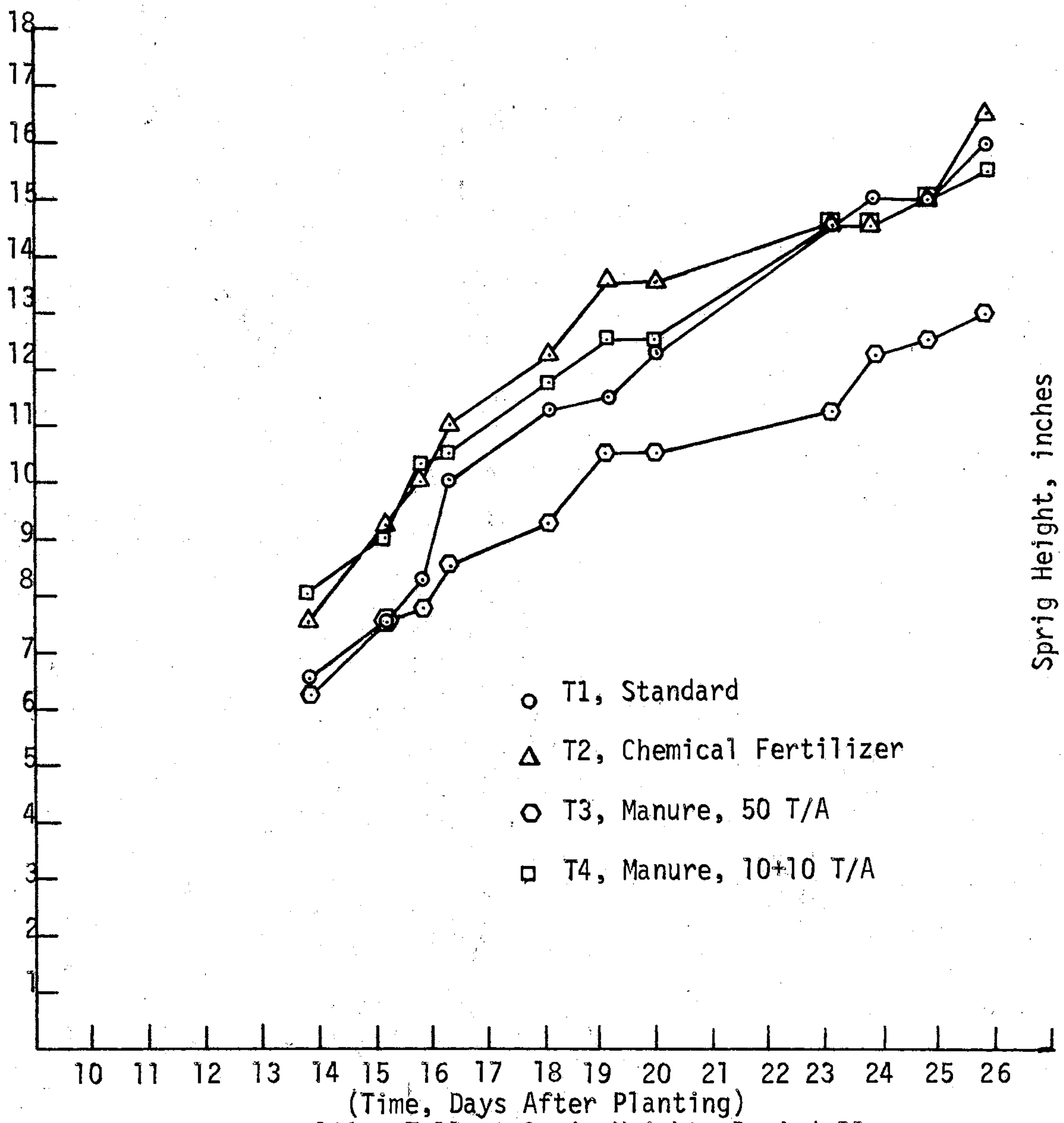


Figure 19A. Tallest Sprig Height, Period II

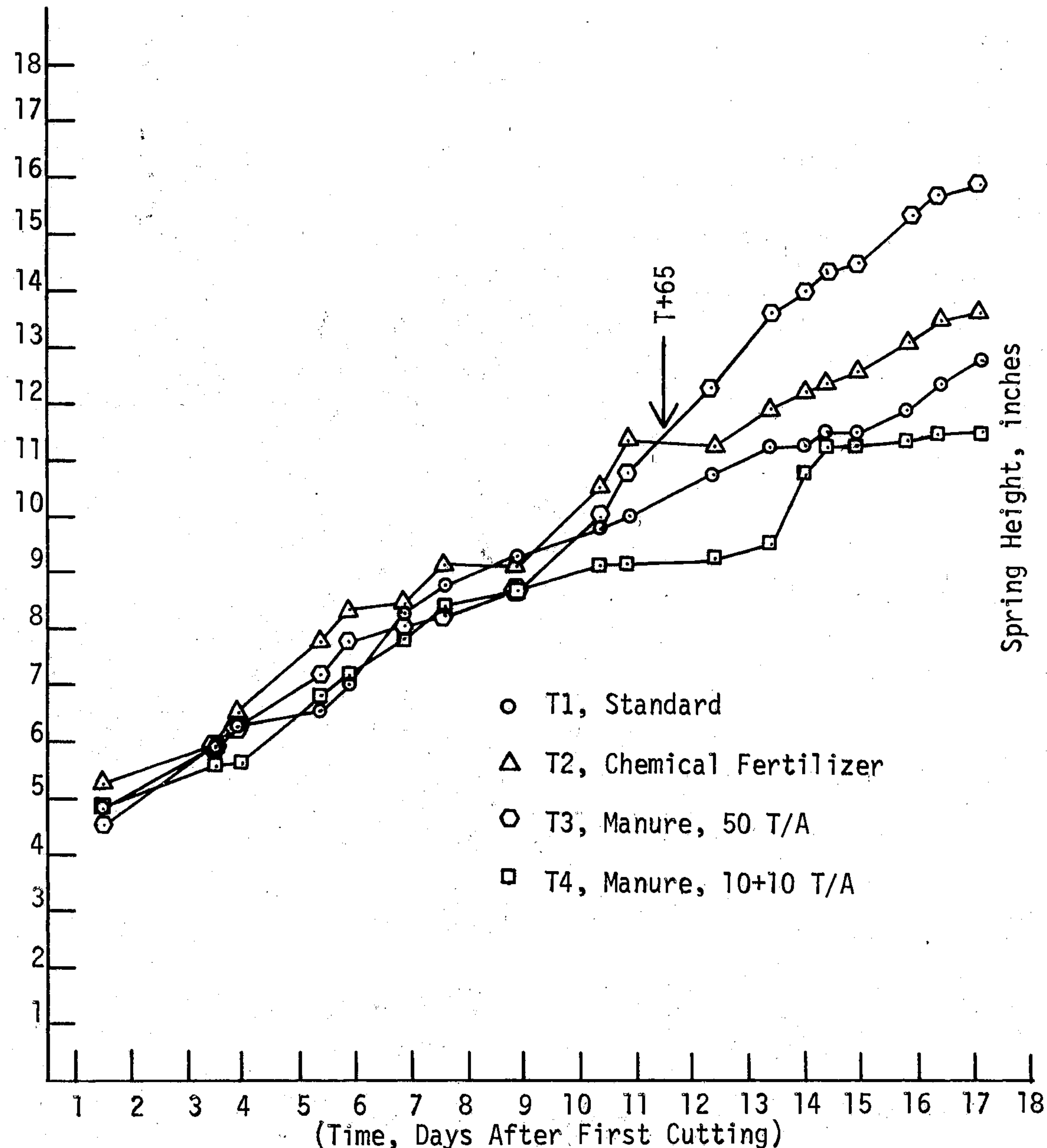
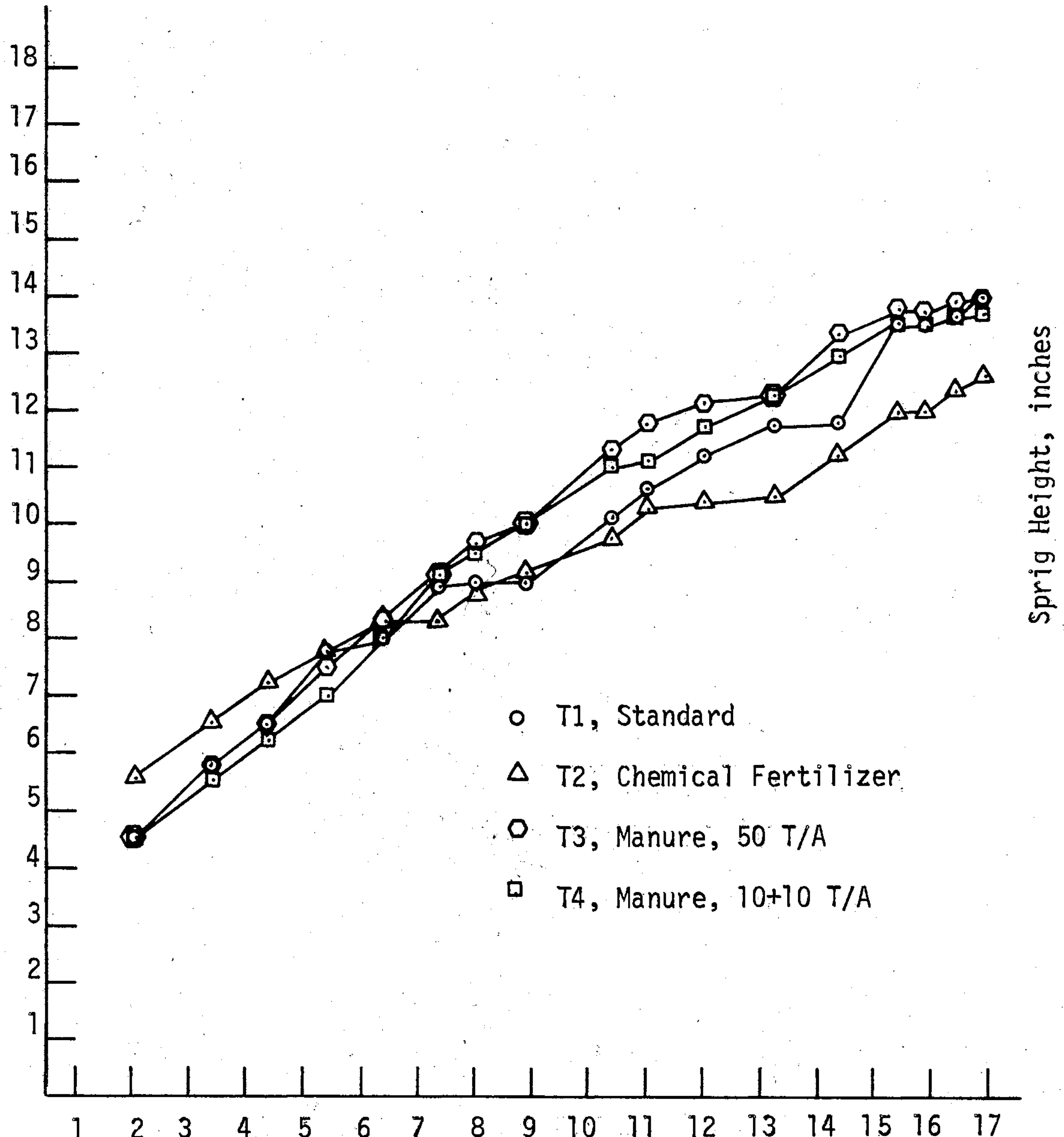


Figure 19B. Tallest Sprig Height, Period III



(Time, Days After Second Cutting)

Figure 19C. Tallest Sprig Height, Period IV

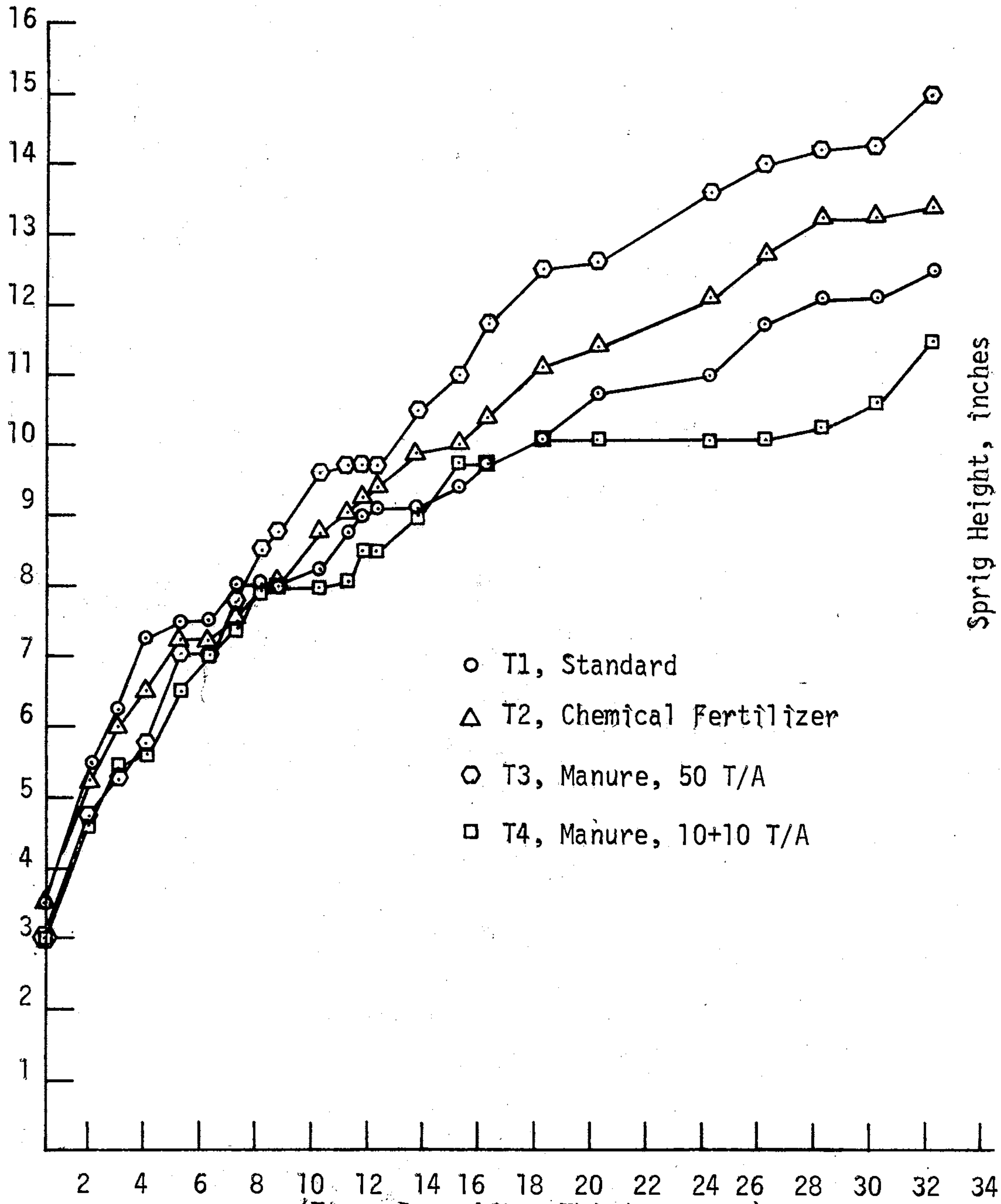


Figure 19D. Tallest Sprig Height, Period V

Tank	Dry Matter (gm)	Percent Dry Wt.	Percent STD
T1	1.00	31.4	100
T2	1.59	27.3	158
T3	2.15	28.0	215
T4	1.30	27.0	130

The total yield comparison is shown below:

Tank	Dry Matter (gm)	Percent Dry Wt.	Percent STD
T1	7.15	19.6	100
T2	9.23	19.3	129.0
T3	7.62	21.2	106.4
T4	9.04	18.9	126.2

Note that the percent dry weight in T3 is two percent higher than in T2.

Figure 20 is a plot of the rate of dry matter production per day during each of the periods. Note the stunted growth of T3 during period II, and the higher rate of yield during periods IV and V.

Figure 21 shows a graph of the cumulative dry matter yield. The total yield was highest in T2; 129 percent of standard.

2. Plant Protein

Listed below is a comparison of the protein content of the grass grown during periods III, IV, and V. The protein content of the grass from T2 was slightly higher than from T3. There was a significant decrease in the protein content of all tanks with each successive period.

Period	Tank	Protein Content, Percent
III	T1	22.2
	T2	24.6
	T3	23.8
	T4	24.4
IV	T1	20.0
	T2	22.7
	T3	21.1
	T4	20.8

Period	Tank	Protein Content, Percent
V	T1	15.4
	T2	16.9
	T3	16.7
	T4	15.6

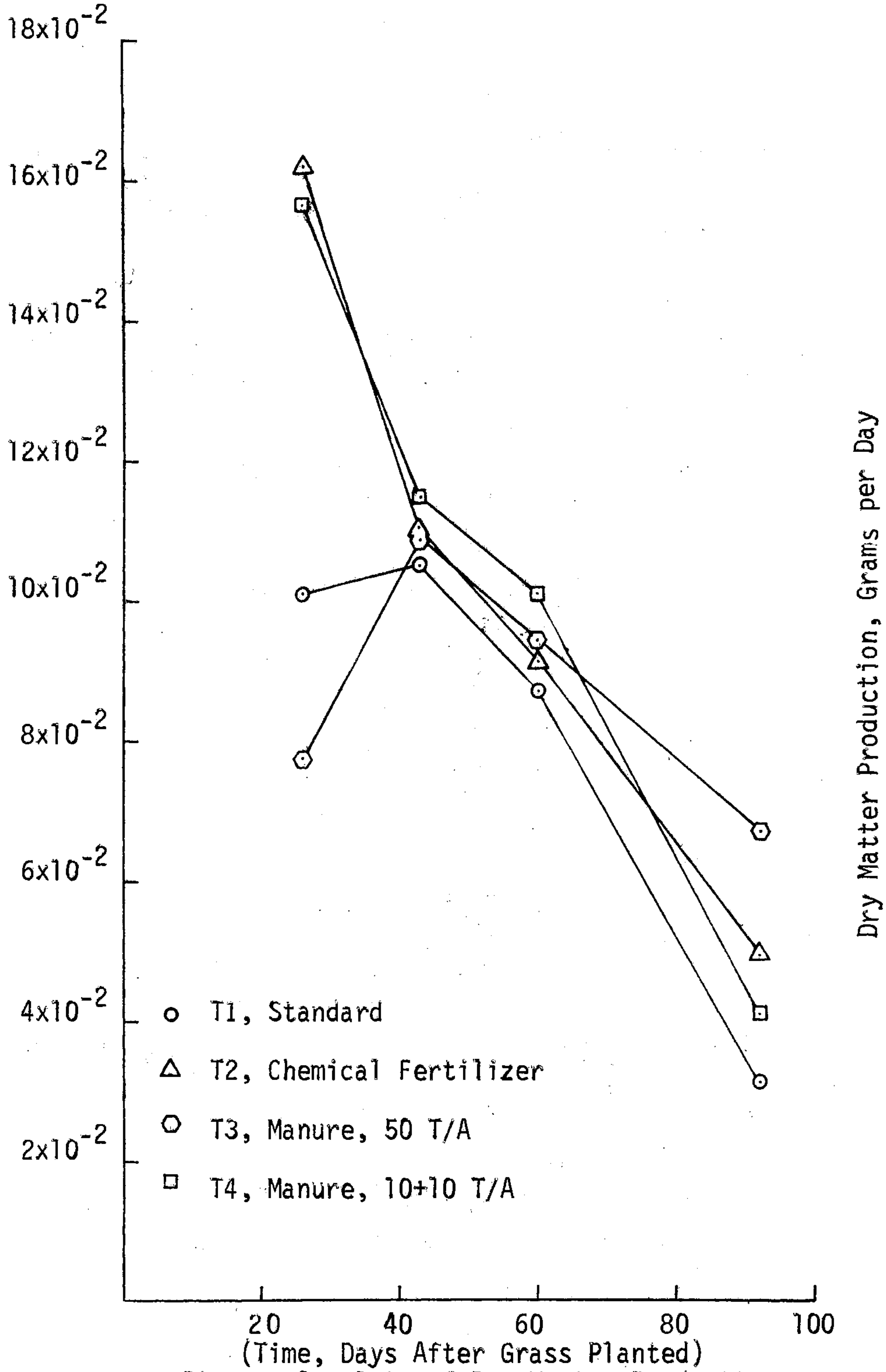


Figure 20. Rate of Dry Matter Production

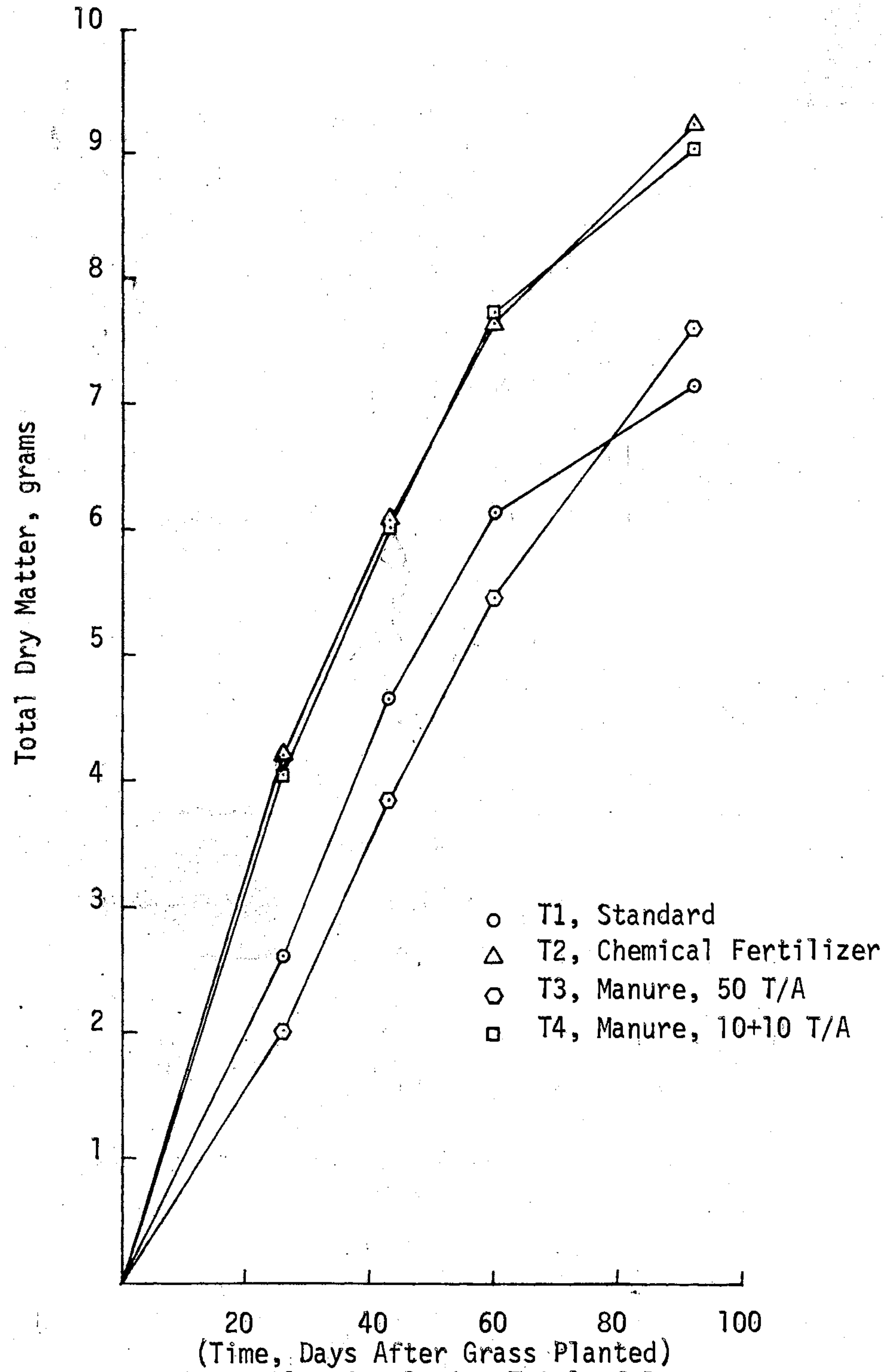


Figure 21. Cumulative Total of Dry Matter Produced

CHAPTER V

DISCUSSION

A. Soil Moisture

1. Infiltration Rate

The infiltration rate, as shown in Figure 9, increased in all tanks and the same basic pattern in all tanks indicated that initially each of the tanks did, in fact, contain soil that had very similar characteristics. However, between T+54 and T+71, or during period III, a significant change had occurred in the tanks with the manure added, to cause a significant increase in the ability of the soil to absorb water. Since the only significant difference in the tanks was the organic matter added, the change is attributed to changes in the soil as a result of the biological action on the manure and corresponding effects on the physical properties of the soil, such as increasing the pore size of the soil. This conditioning of the soil is a significant enhancement in that the soil will absorb more water and allow less runoff from rainstorms. This should be of particular interest and value to farmers in the southwest, where rainstorms are normally short and relatively severe, with high runoff rates.

Although there were no measurements made directly to determine the erosion resistance of the test plots, it is deduced that erosion would be reduced in soils that had a high infiltration rate. This deduction is supported by data from research conducted in vineyards in Germany, as discussed in Section L-2, Chapter II (page 37) herein.

During period IV, an ant colony grew in T2 and made a vertical track along one side of the tank. This track was large enough to allow water to flow immediately through the tank. Therefore, Figure 9 has a solid line for the actual rate and a dotted line for the estimated rate had the ant path not provided additional free access into the soil. As soon as the ponded water had all infiltrated, the response of the tank returned to normal, and the ant paths seemed to have little or no effect on the water movement.

It was interesting to note the drop in the infiltration rate of T4 after the 10 tons/acre of manure was added in the water at the beginning of period III at T+54. This probably occurred because the green manure clogged the pores of the soil. However, note that by T+71, this layer of manure at the surface created a condition that caused the infiltration rate to increase sharply with respect to all other tanks. This effect may be attributed to increase in the biological activity at the surface due to the concentration of the organic matter there.

2. Water Percolation Rate and Free Water

The rate of percolation in the tanks was computed by measuring the amount of time required for free water to appear at the bottom of the soil column after the first water was poured into the tank. The similarity of all tanks to T+54 again confirms the similarity of the soil in all tanks at the beginning of the experiment. The general increase in the percolation rate after T+54 may be attributed to the developing of the root system providing avenues for the water to travel and to stabilization of the soil. Again, the ant paths in T2 provided an immediate route for water percolation to the bottom of the tank, as shown by the solid line in Figure 10. The dotted line from T+71 is what the rate actually was at other places in the soil where the ant paths did not exist, and considering the time water began to drip from the bottom of the tank at places other than at the ant paths.

It is interesting to note the difference in the pattern of the percolation rate between T3 and T4. The rate in T3 increased very little, and it appears that the effect of the heavy manure was to increase infiltration rate but retard the percolation rate of the water. The effect in T4 was just the opposite. The differences in T3 and T4 were amount and method of application of manure. The effect appears to be more from the method of application than from the amount, since it seems that a smaller amount would mean a smaller effect but in the same direction. This was not the case. The effect could be caused partially by the inertia of water as a result of the higher infiltration in T4, and partially by some effect of the biological action in the surface area. However, there is a possibility that, beginning at zero and increasing the application rate of manure, there is an oscillation that would result in an initial increase in infiltration rate at the lower application rates. This hypothesis perhaps is supported by the fact that T3 showed a rather significant oscillation in the amount of free water measured as discussed in Chapter IV, Section A-2 (page 55) herein. The relationship between the free water curves for T2 and T1 reveal that no significant change occurred in the water-holding capacity of the soil treated with chemical fertilizer. The amount of free water discharged from T3, however, reveals significant changes in the water-holding capacity of the soil as a result of the manure treatment. First, there was a decrease in the water-holding capacity, but then throughout the remainder of the experiment the holding capacity continually increased until it was significantly greater than T1 at the fifth watering.

T4 exhibited a different pattern of oscillation with increasing water-holding capacity at the second and third watering, decreasing at the fourth watering, and increasing again at the fifth watering. This effect was probably due to the application of additional manure during the third watering. By the fifth watering, biological activity had occurred to cause the water-holding capacity to begin to increase as in T3.

3. Moisture Tension and Moisture Content

One of the most evident results of this experiment was the change in the moisture tension pattern in the soil as a result of adding the manure and the fertilizer. The addition of chemical fertilizer causes conditions that permitted water to be lost or bound up in the soil faster than the blank soil. Some of the water lost during the first growing period could be accounted for in the higher yield. However, the same relationship existed in every period, even when the yield in T2 was less than in T3. There was some oscillation between T3 and T4, with T4 exhibiting some seemingly erratic fluctuations. As discussed in Chapter IV, there was a very positive correlation between the moisture tension in T3 and the moisture content. However, at level 1, during periods III and IV and the first part of period V, there was more moisture content in T4 than in T3, although the tension in T4 was greater than that in T3. The shape of the moisture release curve for T4 was considerably different from the other tanks at that level. Therefore, if an experimental error occurred, it was in determining the moisture release data. To check this possibility, a comparison of the moisture content obtained from the curve on the last day of period V was compared with the moisture content determined from a grab sample of soil taken for that purpose at the same time and level the core samples were taken for the moisture release data. These two readings agreed within 0.5 percent, which tends to confirm the validity of the moisture release data. This being the case, it must be accepted until further investigation, that there was a higher moisture content in T4 existing at a higher tension than in T3.

Another significant result was the moisture loss during the night when there was little or no growth and the temperature was down. Under these conditions, the soil in T1 and T2 continued to lose moisture, while the soil in T3 and T4 did not lose moisture during the night. This indicates that most of the water loss in T3 and T4 was going to produce plant growth, while considerable moisture was lost from T1 and T2 by evaporation. This means that the organic matter in T3 and T4 formed a barrier against moisture loss except through transpiration by the plant.

Another significant result was the moisture profile in the tanks. As was indicated by the moisture differential tabulated in Chapter IV, Section A-3 (page 62) herein, the influence of the organic matter in T3 throughout the depth of the soil made it easier for the moisture to move upward as the moisture at the higher levels was extracted by the plants.

This same phenomenon occurred in T4 but less pronounced. This phenomenon is also shown by the fact that the moisture content at level 4 in T3 and T4 was less than T2, level 4. This even profile in T3 and T4 in effect makes more water available to the plant roots for the same amount of rainfall which percolates below the root zone.

The most significant change in the bulk density of the soil was in the surface layer of T3 where the heavy concentration of manure caused the bulk density to be reduced by 16.5 percent. In fact, there were still pockets of brown humus material existing in the top three inches of T3 when the core samples were taken, and the soil was so friable that it was difficult to take core samples because th soil crumbled out of the core. The effect of the manure on the bulk density extended to the bottom of the tanks, but reduced to a difference of 1.6 percent.

B. Chemical Analyses

1. Nitrate and Ammonia

It was interesting to note the correlation between the response of the soil in T3 and T4 and the stages of nitrification of the manure as it was degraded and stabilized biologically. The beginning of the high buildup in nitrate concentration followed a temporary buildup of ammonia. This lag in the availability of nitrate for use by the plant must be considered in determining the application time of manure relative to planting time. This will be discussed in more detail in connection with a discussion of the growth data in section C below.

Another significant result of tracing the nitrate concentration in the tanks was the confirmation that a large percentage of the nitrates move with the water. This would be a factor where heavy organic loads were placed on the soil and the water table was relatively close to the surface, or where percolation into water supplies was possible. At the rate measured in this experiment, it would take a column of soil 18 feet deep to reduce the nitrate concentration below 5 mg/l.

The nitrate buildup in the standard tank, T1, was probably due to decaying roots and other plant residue.

2. Soil Analyses

Three obvious enhancements occurred in the soil as a result of application of manure compared to chemical fertilizer; the organic matter in T3 increased 100 percent; nutrient levels increased significantly; the cation exchange capacity (CEC) increased by 18 percent in T3, or 12 percent increase over T2.

An evaluation of the phosphorous profile reveals that P does not travel with the water, but is held by the soil.

3. Chemical Oxygen Demand (COD)

The soil effectively removed all of the COD of the manure applied. The COD in T3 effluent was less than standard. This seems to indicate that the ability of the soil to retain organic matter is enhanced when the organic content of the soil is high. Not only was the COD of the manure absorbed, but internal COD from the root decay was held in T3.

C. Plant Height and Weight

Although the primary purpose of this research was to compare changes in the soil and not to evaluate nutrient sources, rough data was recorded regarding plant growth. The data can be used only for speculation, since the amount of sprigs used to start the grass was not closely controlled. Therefore, the initial growth and yield data may or may not be valid. The data near the last of the project would probably make a better comparison except for the fact that the nitrogen applied in T2 was reduced by consumption by the plant.

During the first growing period after the grass was planted, T2 and T4 produced essentially the same growth, while T3 grass seemed to be retarded. This was probably due to the heavy concentration of raw manure applied to only three inches of soil. It took 65 days for the biological processes to prepare the soil for good growing conditions. At T+65, the level of nitrates began a sharp increase, and the height of the grass in T3 overtook the height of the grass in T2. The rate of decrease of grass production by T3 was much slower than any other tank, demonstrating the lasting effect of manure as opposed to the short term effect of the chemical fertilizer. During the first three growing periods, T4, with the light manure treatment, had the highest total yield. However, the growth stoppage in T4 for 10 days during period V caused the total yield of T2 to exceed all others. It is obvious, then, that if manure is to be applied in heavy concentration, it should be applied at least 60 days before plant growth is to start. It should also be noted that manure at the rate of 10 tons/acre provided adequate nutrients to produce good initial growth. During periods of drought, the moisture control of the heavy manure and the sustaining effect on the nutrient level may be an important consideration where water is the prime growth factor.

The grass from T3 contained about two percent less water than did the grass from T2.

D. Plant Protein

The grass from T2 yielded the highest protein content during all three periods tested. Although the difference was very slight, the pattern was consistent. There may be a correlation here with findings in nitrogen content of sugar beets in Japan (14). The protein content of the grass was determined by measuring the organic nitrogen and assuming this to be directly related to protein content. However, since nitrogen in sugar beets decreased with addition of organic matter, as it did in the Bermuda grass, it may be that some phenomenon occurs that makes the crop more digestible even though lower in measurable nitrogen content.

CHAPTER VI

CONCLUSIONS

Based upon the results of this study, it is concluded that:

1. The objectives of the research project were achieved.

2. The addition of manure to a soil low in organic matter significantly enhances the water infiltration rate and the water-holding capacity of the soil, and acts as a water regulator in the soil.

3. The addition of chemical fertilizer alone to a soil of low organic content has a deleterious effect upon the water-holding and regulating capacity of the soil.

4. The addition of 20 tons/acre of raw dairy cow manure maintains the organic matter level in the soil. The addition of 50 tons/acre of raw dairy cow manure increases the organic matter level in the soil.

5. By deductive reasoning, the addition of manure to the soil increased its resistance to erosion.

6. The addition of heavy concentrations of raw manure may initially retard the growth of plants.

7. Application of 10 tons/acre of manure provided adequate nutrients for significant increase in crop yield.

8. It is possible to realize high initial increases in yield of grass using chemical fertilizer even though the organic matter in the soil is low.

9. The Cation Exchange Capacity is significantly increased by applying 50 tons/acre of manure to the soil.

10. The soil friability is significantly enhanced by the addition of manure to the soil.

11. The soil is an extremely efficient system for the removal of COD from such waste as feedlot waste.

12. Nitrates are not efficiently removed by the absorbing or filtering action of the soil.

13. The beneficial effects on the soil as a result of manure application as compared to chemical fertilizer application are of particular importance to the general health of soil such as that in the southwestern part of the United States.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

This research was truly exploratory in nature, and pointed to many areas needing additional research or validation. Some of these areas are:

1. Similar procedures with several different application rates of manure. The soil type should also be varied.

2. Similar procedures using various soil types and application rates of sewage sludge.

3. Field tests to determine correlation between laboratory findings and actual field results.

4. Investigate the application of combinations of organic and chemical fertilizer to correct specific deficiencies in the soil.

5. Determine the cost/effectiveness of the various treatments available.

6. Investigate the nutrient value of crops grown on soil with various amounts of organic matter.

7. Investigate the erosion control characteristics of soil treated with various amounts of organic and chemical fertilizer.

8. Investigate the prolonged effect on soil of oxidizing the organic matter without replacing the organic matter.

9. Investigate the effect of continuous irrigation on the oxidation of the organic matter in the soil.

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