THE EFFECT OF LEAD ARSENATE AND DDT IN SOILS ON PLANT GROWTH

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THE EFFECT OF LEAD ARSENATE AND DDT

IN SOILS ON PLANT GROWTH

By

James A. Porter

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INTRODUCTION AND LITERATURE REVIEW

The following of spray schedules recommended for control of insects and diseases releases over each acre amounts of materials which may be significant in their effects on soils. The amounts of some of the more common materials applied each year per acre were computed, based on Michigan State College recommendations (17). Using the apple schedule as an example and allowing six trees coverage per 100 gallons of spray there could be a total release per acre per season of 84 pounds lead arsenate, 16 pounds DDT and 270 pounds sulfur. Other spray schedules have called for even more lead arsenate. Overley (18) computes the lead arsenate in some Washington orchards as totaling 4500 pounds lead arsenate per acre over a 10-year period. Other materials are included in the spray recommendations but quantities were not included here.

It can be presumed that unless the spray ingredients evaporate, undergo chemical change, are removed with the fruit, or remain on the tree itself they will ultimately reach the soil. Even most of that carried on the leaves will reach the soil since most of the leaf fall remains within the orchard.

One of the effects of sulfur is apparent from a study of soil reaction within Michigan orchards, where the spray schedules include sulfur. Consistently soil tests beneath these fruit trees, 10 years or more in age, show higher acidity than soils in adjacent locations between the trees. The 270 pounds of elemental sulfur per acre per year would have a potential acidity equivalent to 852 pounds limestone on the chemical equivalent basis. Soil reactions have frequently been observed which varied from pH 5.0 between trees to below pH 4.0 under the trees in long established orchards.

This investigation is directed primarily at effects of the insecticide lead arsenate. Because lead arsenate has, since about 1947, been largely or completely replaced in many spray schedules by DDT, some of the investigations included this latter material.

Many investigators have shown that growth of plants is retarded on soils in orchards where spray schedules have included lead arsenate. Studies by Overley (18) in Washington orchards were based on failure of cover crops. Snyder (20) observed growth of a new planting of apple and pear trees on a site where old orchard trees had been removed. Only those trees planted in soil hauled in were normal and made satisfactory growth; other trees and vegetables failed. Vandecaveye et al (21) reported failure of barley and alfalfa following removal of a 27 year old orchard.

Cation (4) reported partial failure of strawberries on the site of an old apple orchard in Berrien County, Michigan. Within the area previously covered by each tree, growth was greatly retarded. Soil samples from the areas of good and poor growth were analyzed for content of arsenic.* The arsenic content of soil from the area of poor strawberry growth was 292.5 parts per million As_2O_3 while in areas of normal growth the content was 69.3 parts per

* Analyses for arsenic were made by Dr. E. J. Benne, Agricultural Chemist, Michigan Agricultural Experiment Station, East Lansing.

million. At the time of a subsequent visit to this old orchard site Sudan grass had been sown as a cover crop. There was a noticeable difference in growth in regularly spaced areas presumed to correspond with former apple tree locations. In this case the analysis for arsenic did not show a striking difference: the content in the poor growth area was 220 and in the better growth area 192 parts per million As_2O_3.

That it is the anion, not the cation of lead arsenate which results in poor growth has been quite definitely established by Overley (18). In greenhouse experiments from one to five tons per acre of lead arsenate was mixed with Palouse soil and equivalent quantities of lead as acetate and nitrate salts. Alfalfa was planted and one ton of lead arsenate resulted in 98 percent death of a five percent stand. In contrast, lead acetate at one ton resulted in a 100 percent growth of a 100 percent stand and five tons decreased the stand to only 70 percent. By injecting sodium arsenate and lead acetate into peach trees Linder (15) proved that damage was from arsenic -- not the lead.

In natural soils plants do not grow in total absence of arsenic. Williams and Whitestone (23) report the arsenic content of a geographically wide range of soils representing many great soil groups. They report the natural content ranging from 0.3 to nearly 40 parts per million arsenic as As. There seems to be no consistent distribution of arsenic in soil with regard to depth in profile, latitude nor precipitation. Rarely do soils reported contain more than 12 parts per million As.

Reports of plant growth retarding effects attributed to DDT (dichloro-diphenel-trichloroethane) were few. That this insecticide does affect biological relationships in the soil has been investigated. Jones (14) found the nitrification, ammonification and sulfur oxidizing microorganisms were not affected at concentration of less than 0.1 percent DDT (50%) or 2000 pounds per acre. There was a retardation at 1 percent. There was no injury to nitrogen fixing microorganisms at concentration of 1 percent DDT (50%). On the other hand, Wilson (24) found no effect on bacterial numbers, ammonification or nitrifying bacteria at concentrations of 5 percent DDT in soil. Smith (19) found no injury to growth up to 400 pounds per acre. Appleman (3) worked with concentrations of 10, 100 and 1000 pounds DDT (98%) per acre worked into the surface two inches of soil. Emergence of red clover, sweet clover and lespedeza was only slightly delayed and soybean emergence delayed seven days. All species showed growth inversely proportional to amount of DDT mixed with soil. Little adverse effect was observed at concentrations of less than 100 pounds of DDT per acre. Some of the confliction in results, reported by various investigators, on injurious effects of DDT may be attributable to impurities.

This study, in its first phase, involved the growth of plants on soil from the area from which apple trees had been recently removed, the Berrien County, Michigan area referred to previously.

This was followed by investigations of plant growth in soils with which had been incorporated measured increments of lead arsenate; also, in a similar way, DDT was included in this phase of the investigation.

EXPERIMENTAL PROCEDURE

All the plant growth studies were conducted in a Michigan State College greenhouse at East Lansing, Michigan. Soils were contained in number two glazed earthenware pots. Watering was with distilled water from the greenhouse still.

The initial phase of the investigation involved the study of plant growth in Hillsdale sandy loam from a field in Berrien County, Michigan, from which an apple orchard had been recently removed. The soil was screened through standard one quarter inch screen and a representative sample was tested and reported as containing 220 parts per million total As_2O_3. This would be equivalent to 770 parts per million or 1540 pounds per acre*, in terms of lead arsenate**.

This soil, which will be designated in this paper as "orchard soil", was used alone and mixed with three increments of uncontaminated Oshtemo loamy sand, and the Oshtemo alone. The soil had been collected from the Rose Lake Game Research Farm of the Michigan Department of Conservation, screened and stocked in the Experiment Station Soil Science field laboratory. The soils were air dry and combined in a hand operated tumbling mixer.

Eight kilograms of these mixtures were used per pot in two series with three replications, one series having no fertilizer

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* In terms of plow layer weighing 2,000,000 pounds.

** $PbHAsO_4$

added and the other receiving commercial fertilizer carrying the manufacturers guarantee of three percent by weight nitrogen (N), 12 percent phosphoric acid (P_2O_5) and 12 percent potash (K_2O); this fertilizer was applied at a rate equivalent to 750 pounds per acre. The fertilizer was added at the time the soils were mixed.

Bean Plant Growth

Each pot received 1,000 grams of water on December 29, 1948. Ten navy beans* were planted per pot on December 30 and later thinned to five plants. On February 26 the beans were clipped one quarter inch above the soil surface, and air dried before weighing. At the time of harvesting observations were made of bean root nodulation.

Tomato Plant Growth

On March 5 following the removal of bean plants, the same soils were worked to a depth of about four inches and one tomato plant was set in each pot. No additional fertilizer was applied. The tomatoes were harvested after some of the fruits had ripened. The fruits were dried in a heated forced air drying oven before weighing, and the weights were recorded separately from the plant weights.

Sudan Grass

Studies were expanded to include the insecticide DDT in addition to lead arsenate. These materials were mixed at various rates with two soils, Oshtemo loamy sand and Hillsdale sandy loam.

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* Phaseolus vulgaris.

The Oshtemo loamy sand was from the same source as that used in the previous investigation. The Hillsdale sandy loam was collected from the college farm and screened through a mechanically operated cylindrical one quarter inch sieve. In addition to the screening, the soil was systematically shoveled-over three times before taking it to the greenhouse. Here the soil was placed on waxed paper covered greenhouse benches for air drying before weighing.

Soils were weighed into number two glazed earthenware pots, nine kilograms air dry weight per pot. Standard spray grade lead arsenate and 50% Wetable DDT were added at the rates shown in Table I.

TABLE I

QUANTITIES OF LEAD ARSENATE AND DDT MIXED WITH SOIL

Material	Grams per pot, containing nine kilograms soil	Equivalent rate per acre—2,000,000 pounds soil
Lead arsenate	0	0
	0.3	150
	0.6	300
	1.2	600
	2.4	1200
DDT - 50%	0	0
	0.3	75
	0.6	150
	1.2	300
	2.4	600

All pots were fertilized with a mixture of ammonium sulfate and 0-20-20 commercial fertilizer at a rate equivalent to 80 pounds each per acre of nitrogen (N), phosphoric acid (P_2O_5) and potash (K_2O).

Each pot of weighed soil was poured onto the fabric side of a square of oil cloth in a three inch layer and the material or materials to be admixed were scattered uniformly over the surface. After an extensive hand stiring, the mixing process was completed by raising and lowering successively the corners of the cloth in such a manner as to subject the soil to a rotary rolling action, after which the soil was returned to the pot. Each treatment was in three replications.

The crops selected for planting were Sudan grass* to be followed by soybeans. Sudan grass was selected because it was one of the crops, the growth of which had been observed as being depressed in the Berrien County orchard site field previously mentioned.

The pots were watered at rates of 800 grams per pot of Oshtemo loamy sand and 1,000 grams for the Hillsdale sandy loam. Initial watering of the air dry soil was November 11, 1950 and the Sudan grass seeded November 17. An attempt was made to maintain a stand of 12 plants per pot. The plants were cut at the soil surface February 3, 1951 at which time many of the larger plants were in flower. The grass was air dried in the greenhouse before weighing.

After removal of the Sudan grass the soils were loosened in

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* Sorghum vulgare var. Sudanese.

the pots, brought up to weight with water and soybeans* were planted. This crop was selected for the purpose of making further observations of the effect of arsenic and also of DDT on legume nodulation. The effect on growth is also important since soybeans are adapted to use as green manure, and the increasing of organic matter content of soil is reported as an effective measure in reducing arsenic toxicity (18). Twenty inoculated beans were planted in each pot and were later thinned to eight plants per pot.

When flowering began the plants were removed by cutting one inch above the soil surface. The tops were air dried in the greenhouse and weighed.

Immediately after removal of tops the roots were removed by gently prying the soil into a loose condition. The root mass with as much soil as possible was removed and gently agitated in a pail of water until enough soil was removed to permit counting of nodules on roots. Each nodule was counted, regardless of size. There appeared to be roughly the same size range of nodules on each plant. Some of the larger nodules had more than one, and up to four divisions or lobes. These lobes were ignored unless the division between them carried well to the base, in which case it was counted as a separate nodule. The total number of nodules per pot was recorded.

It was thought that this method might leave some nodules torn loose from the root to remain in the soil unrecorded. In one case

* Glycine hispida.

of two plots which appeared to be representative with respect to nodule formation, an intensive examination was made of the soil and especially of the fine rootlets. No nodules were found.

RESULTS AND DISCUSSION

Growth Response of Plants to Soil Mixtures of Varying Proportions of Old Orchard Site and Normal Soils

Navy beans. An analysis of the bean growth data in Table II shows significant increases in yield through increasing the proportion of normal soil in both the fertilized and unfertilized series. The final increment of normal soil to 100 percent failed to show an increase, however, in both series. This appears to be attributable to a secondary influence on plant growth; the variation in fertility level of the two soils which is indicated by soil tests.* This difference is shown in Table II and graphically in Figure 1 by the higher yield in the mixture containing 25 percent "orchard" compared with 100 percent normal soil. Apparently at this level the increased fertility was more beneficial to plant growth than the accompanying arsenic was detrimental. This influence is more pronounced on the unfertilized series, a further indication of basic fertility difference.

The yield levels are generally higher in the fertilized than in the unfertilized series. The growth-depressing affect of the orchard soil is more marked in the unfertilized series.

The orchard soil, as mentioned previously, contained 220 parts per million of As_2O_3. This is equivalent to 770 parts per million

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* Soil test: Orchard soil - pH 5.4, P - 34 lbs. and K - 165 lbs. per acre. Oshtemo loamy sand - pH 5.1, P - 27 lbs. and K - 19 lbs. per acre. (P and K extracted with 0.13 N HCl).

TABLE II

EFFECT OF VARYING THE PROPORTIONS OF ARSENIC-CONTAINING* AND NORMAL SOIL ON THE AIR-DRY WEIGHT OF NAVY BEAN PLANTS, WITH AND WITHOUT FERTILIZER

Pot Number	Soil Mixture: Arsenic	Soil Mixture: Normal	Equivalent As_2O_3 per A.	Weight of Plants: Per Pot	Weight of Plants: Treat. Ave.
	percent	percent	pounds	grams	grams
			no fertilizer		
1	100	0	1400	2.3	
2	"	"	"	1.7	1.80
3	"	"	"	1.4	
4	75	25	1050	1.9	
5	"	"	"	2.9	2.47
6	"	"	"	2.6	
7	50	50	700	2.[illegible]	
8	"	"	"	[illegible]	3.[illegible]**
9	"	"	"	[illegible]	
10	25	75	350	3.4	
11	"	"	"	3.7	3.57**
12	"	"	"	3.9	
13	0	100	0	3.1	
14	"	"	"	2.7	2.63
15	"	"	"	2.1	
	Least significant difference at 5%: [illegible]				
			250 pounds per acre of 3-12-12		
16	100	0	1400	1.9	
17	"	"	"	.9	1.57
18	"	"	"	1.9	
19	75	25	1050	2.9	
20	"	"	"	2.3	[illegible].70**
21	"	"	"	2.9	
22	50	50	700	[illegible]	
23	"	"	"	2.5	3.[illegible]**
24	"	"	"	3.9	
25	25	75	350	[illegible]	
26	"	"	"	4.5	4.[illegible]**
27	"	"	"	4.7	
28	0	[illegible]	0	4.[illegible]	
29	"	"	"	5.5	4.[illegible]*
30	"	"	"	4.3	
	Least significant difference at 5%: [illegible]				

* Orchard soil (arsenic contaminated).

** Significantly different at 5%.

FIGURE 1. NAVY BEAN GROWTH AS IT IS AFFECTED BY VARYING THE PROPORTIONS OF ARSENIC-CONTAMINATED (ORCHARD) AND NORMAL SOIL WITH AND WITHOUT FERTILIZER

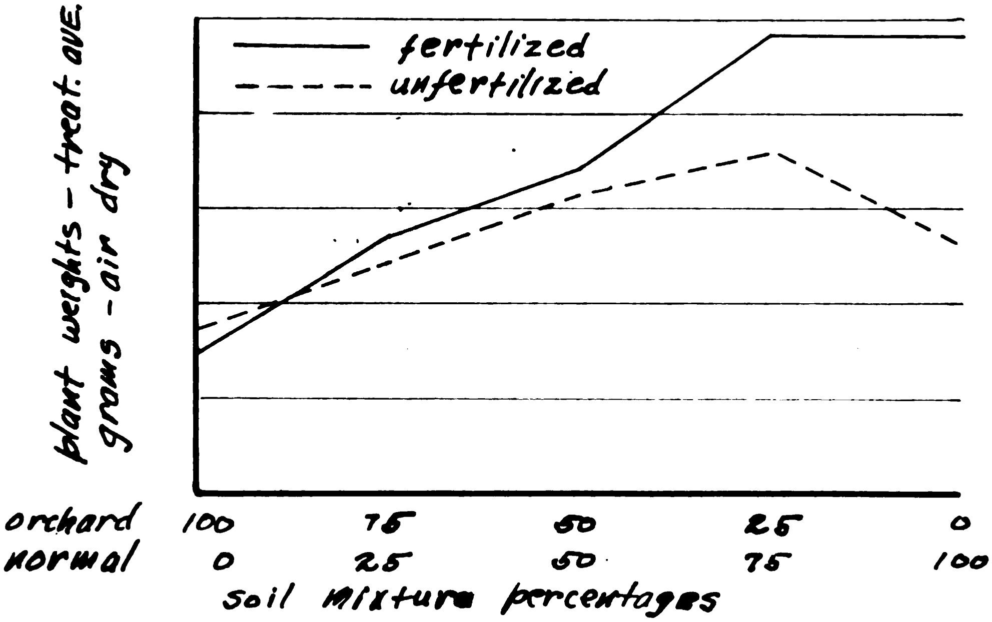
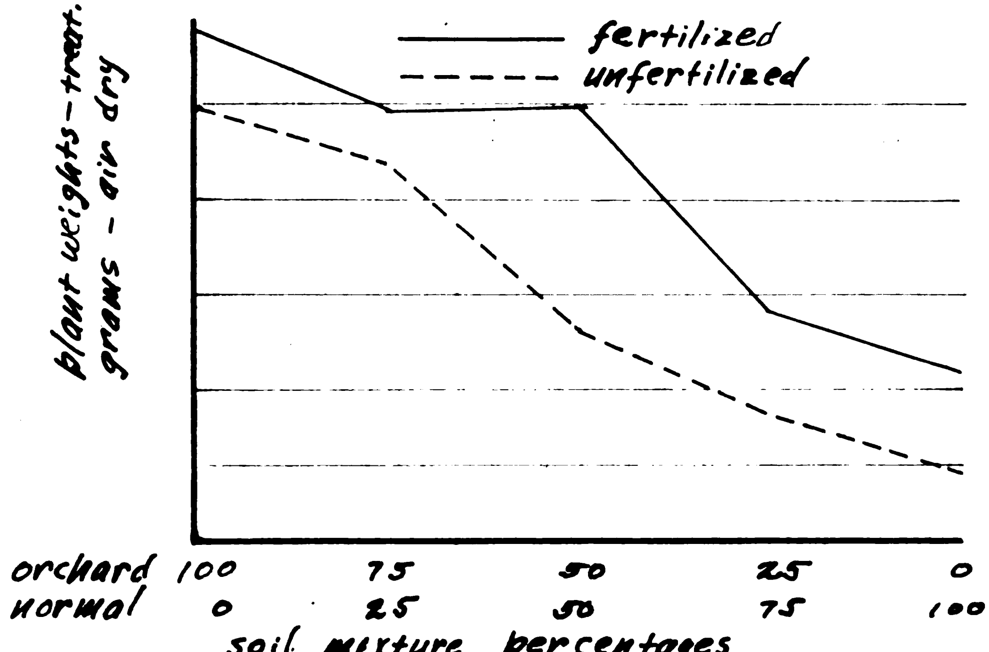


FIGURE 2. TOMATO PLANT GROWTH AS IT IS AFFECTED BY VARYING THE PROPORTIONS OF ARSENIC-CONTAMINATED (ORCHARD) AND NORMAL SOIL, WITH AND WITHOUT FERTILIZER



of lead arsenate or 1440 pounds per acre. On the basis of this calculation the arsenic content for each soil mixture is shown in Tables II and III. There was apparently a fair degree of tolerance to arsenic at a concentration of 360 pounds lead arsenate equivalent per acre. This differs somewhat with the results of the experiment in which lead arsenate was laboratory-mixed with soil, data in Table IV, in which growth depression was observed at the 150 pounds per acre level. The higher toxicity resulting from laboratory admixing may be due to a difference in solubility. Under conditions of slow accumulation in soil under field conditions it may become fixed and consequently less soluble.

That there is a wide range of arsenic solubility is suggested by Overley (18) who reports on sixteen Washington orchard soil samples a range of 366 to 723 parts per million total arsenic and 13.2 to 35.5 parts per million water soluble. Some type of arsenic fixation is implied. Albert (2) reports a slow fixation of arsenic in sandy soils of South Carolina and shows that iron is involved in this action. Vincent (22) found that the growing of rye and plowing it under as a green manure was effective in reducing arsenic toxicity. He attributes this to the increase of organic matter. Overley (18) found the addition of peat and also superphosphate effective in reducing arsenic toxicity. This confirmed similar benefits from phosphorus reported by Hurd-Karrer (11). Not all investigators agree on the effect of phosphorus on the solubility of arsenic. Albert (2) reports that superphosphate increases arsenic

TABLE III

EFFECT OF VARYING THE PROPORTIONS OF ARSENIC-CONTAINING AND NORMAL SOIL ON THE AIR DRY WEIGHT OF TOMATOES, WITH AND WITHOUT FERTILIZER

Jar Number	Soil Mixture: Arsenic	Soil Mixture: Normal	Equivalent As_2O_3 per A.	Air Dry Weight of Plants: Vine	Fruit	Vine + Fruit	Treatment Ave.
	percent by weight		pounds	grams	grams	grams	grams
			no fertilizer				
1	100	0	1440	13.6	8.0	21.6	
2	"	"	"	11.8	13.6	25.4	23.1
3	"	"	"	7.6	14.7	22.3	
4	75	25	1080	12.5	8.8	21.3	
5	"	"	"	9.9	7.5	17.4	20.2
6	"	"	"	10.5	[illegible]	21.0	
7	[illegible]	50	720	6.5	8.3	[illegible]	
8	"	"	"	4.2	3.1	7.3	11.2
9	"	"	"	5.9	5.7	11.6	
10	25	75	360	2.1	3.9	6.0	
11	"	"	"	missing	missing	---	6.9
12	"	"	"	3.6	4.2	7.8	
13	0	100	0	missing	missing	---	
14	"	"	"	3.6	0	3.6	3.9
15	"	"	"	4.2	0	4.2	
		Least significant difference at 5% 3.34 and 4.25					
		3-12-12 fertilizer at 750 pounds per acre					
16	100	0	1440	13.2	13.5	26.7	
17	"	"	"	missing	7.2	---	27.2
18	"	"	"	16.0	11.7	27.7	
19	75	25	1080	10.1	9.2	19.3	
20	"	"	"	11.5	14.8	26.3	23.0
21	"	"	"	14.8	8.5	23.3	
22	50	50	720	[illegible]	[illegible]	[illegible]	
23	"	"	"	13.7	8.6	22.3	23.1
24	"	"	"	11.2	12.8	24.0	
25	25	75	360	7.0	0	7.0	
26	"	"	"	10.0	8.7	18.7	13.5
27	"	"	"	6.8	8.0	14.8	
28	0	100	0	5.0	4.5	9.5	
29	"	"	"	6.3	8.6	14.9	8.9
30	"	"	"	[illegible]	6.3	12.3	
		Least significant difference at 5% [illegible]					

solubility.

Bean growth characteristics. The navy beans, planted December 30, did not appear to be delayed in emergence. By January 14 the second leaves were well formed and there was no apparent difference in growth, either between treatments, proportions of orchard soil, or between series, fertilized and unfertilized. The results are shown in Plate I.

By February 1 there was a noticeable difference in growth between treatments. The growth was inversely proportional to the percentage of orchard soil. Appearance of the bean plants at harvest time is shown in Plates II and III.

Accompanying the retardation of growth there developed a watery breakdown of the lower-borne leaves of plants in the higher percentages of orchard soil. The breakdown would spread over the entire surface of a leaf within a day or two, the leaf would dry, although remaining green, and fall from the plant. Besides this most common symptom there were two types of progressive leaf chlorosis, one type starting in the interveinal region and the other in a pattern of irregular blotching. These are shown in Plates III and IV. In so far as possible, the fallen leaves were identified with the pots containing the plants from which they fell and preserved for inclusion with the plants at weighing.

As was previously mentioned, an observation of the bean roots for nodulation was made at the time the soils were being reworked in preparation for the next planting — tomatoes. There were several

PLATE I

NAVY BEANS, 16 DAYS AFTER PLANTING, GROWING IN VARYING PROPORTIONS OF ORCHARD AND NORMAL SOILS. FIGURES ON POTS REFER TO PERCENT ORCHARD (ARSENIC CONTAMINATED) SOIL.

A. Unfertilized.

B. Fertilized with 3-12-12 at 750 pounds per acre.

PLATE II

NAVY BEANS, 52 DAYS AFTER PLANTING, GROWING IN VARYING PROPORTIONS OF ORCHARD AND NORMAL SOILS. FIGURES ON POTS REFER TO PERCENT ORCHARD (ARSENIC CONTAMINATED) SOIL.

A. Unfertilized.

B. Fertilized with 3-12-12 at 750 pounds per acre.

PLATE III

NAVY BEANS, 52 DAYS AFTER PLANTING SHOWING TYPE OF GROWTH. IN BOTH (A) AND (B) THE PLANT ON THE LEFT IS IN NORMAL SOIL, THE ONE ON THE RIGHT, ORCHARD (ARSENIC CONTAMINATED).

A. Unfertilized.

B. Fertilized with 3-12-12 at 750 pounds per acre.

PLATE IV

BEAN LEAVES FROM PLANTS GROWN IN ARSENIC CONTAMINATED (ORCHARD) SOIL, EXCEPT THE ONE ON THE LEFT FROM PLANT GROWN IN NORMAL SOIL

nodules in the normal soil pots but only one was found in the orchard soil mixtures; that, in one of the 50 percent orchard soil pots.

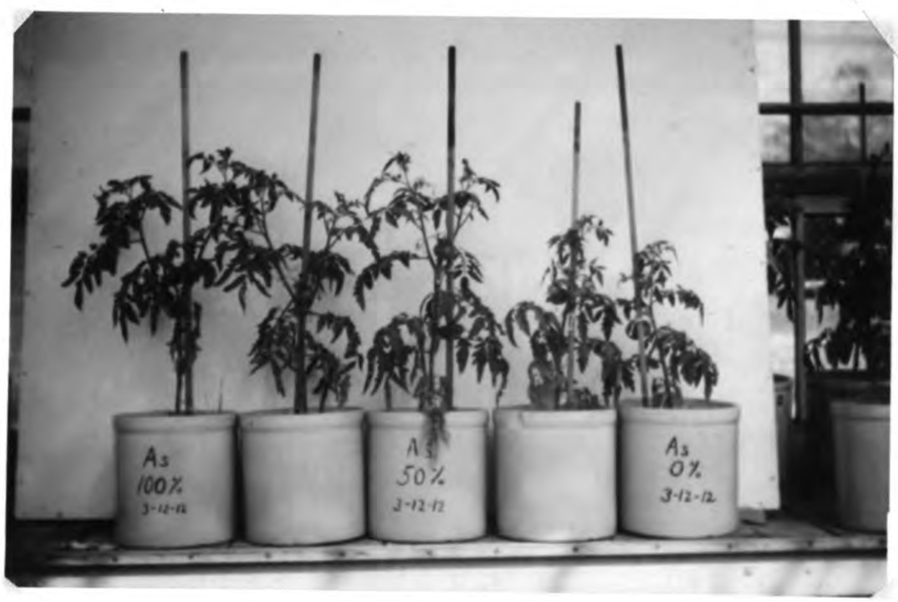
__Tomato investigations.__ Tomato yield data in Table III show two things: the crop is highly resistant to arsenic toxicity and the difference in basic fertility of the two soils is highly significant. The growth-trend differences between navy beans and tomatoes can be readily seen by comparing Figures 1 and 2, and Plates II and V.

Perhaps of sufficient interest to justify mentioning here were the three single pot treatments using the unfertilized Oshtemo loamy sand (normal soil) with increments of arsenic amounting to 875, 1,750 and 3,500 pounds lead arsenate per acre corresponding to 250, 500 and 1,000 pounds As_2O_5. This was not in the original plan of experimentation and it may be of little significance. Plate VI shows these three pots together with a typical control pot of unfertilized, 100 percent normal soil. This print was prepared from a color transparency, showing the deep green leaf color which may be a symptom of phosphorus starvation (6). This condition may be phosphorus deficiency due to what Hurd-Karrer (12) hypothecates as being mass antagonism of two similar ions. He gives a ratio of available phosphorus to arsenic of 5:1 as being protective from arsenic toxicity. Is it possible that in the case of a plant highly tolerant to arsenic the antagonism of a high concentration of arsenic would prevent uptake of phosphorus by roots to the point

PLATE V

TOMATO PLANTS GROWING IN VARYING PROPORTIONS OF NORMAL AND ORCHARD (ARSENIC CONTAMINATED) SOIL. LEFT TO RIGHT: 100, 75, 50, 25 AND 0 PERCENT ORCHARD SOIL

A. Unfertilized.



B. Fertilized with 3-12-12 at 750 pounds per acre.

PLATE VI

TOMATO PLANTS GROWING IN OSHTEMO LOAMY SAND TREATED WITH LEAD ARSENATE IN CONCENTRATIONS, LEFT TO RIGHT, EQUIVALENT TO 3560, 1750, 875 AND 0 POUNDS PER ACRE

where it would show as a phosphorus deficiency symptom? There is certainly an indication that arsenic at higher concentrations is toxic to tomatoes, whatever the nature of the toxicity may be.

McLean (16) in discussing the hazard of toxic amounts of arsenic in plants ventures that there is little danger of arsenic content of plants exceeding the Federal Security Agency maximum tolerance of 3.6 parts per million since plants die before this concentration is reached in the tissues. The highest content he found was in onion tops grown on soil to which had been added 1000 pounds lead arsenate per acre. The most stunted tomato plant in the picture, Plate VI, grew in soil carrying more than three times this concentration.

Growth Response of Plants to Mixtures of Lead Arsenate and DDT with Hillsdale Sandy Loam and Oshtemo Loamy Sand

Lead arsenate - Sudan grass. Each increment of lead arsenate on Hillsdale sandy loam gave a significant depression, compared with the control, in growth of Sudan grass (Table IV and Figure 3). There was not the same relationship in the Oshtemo loamy sand series. In the latter case, there was an increase in plant weight approaching significance from the first increment of lead arsenate, and only the 1200 pounds per acre application resulted in a significant growth depression indicating toxicity.

An explanation of these results is not immediately apparent. First, there is the difference between the two soils in amount of

TABLE IV

EFFECT OF LEAD ARSENATE MIXED WITH HILLSDALE SANDY LOAM AND OSHTEMO LOAMY SAND ON GROWTH OF SUDAN GRASS

Pot Number	Lead Arsenate Per Acre	Plants Harvested	Air Dry Weight of Plants: Total	Air Dry Weight of Plants: Adjusted to 12 plants	Air Dry Weight of Plants: Treatment Average
	pounds		grams	grams	grams
		Hillsdale sandy loam			
16	0	12	96.5	96.5	
17	"	12	95.0	95.0	87.3
18	"	12	70.5	70.5	
19	150	11	42.0	45.8	
20	"	12	51.0	51.0	45.5*
21	"	11	36.5	39.8	
22	300	12	[illegible]	20.0	
23	"	12	17.5	17.5	18.2*
24	"	12	17.0	17.0	
25	600	11	5.0	5.5	
26	"	12	5.0	5.0	5.9*
27	"	11	6.5	7.2	
28	1200	14	3.5	3.0	
29	"	15	4.5	3.6	3.2*
30	"	12	3.0	3.0	
	Least significant difference at 5%			12.8	
		Oshtemo loamy sand			
46	0	12	18.0	18.0	
47	"	12	13.0	13.0	16.6
48	"	12	19.0	19.0	
49	150	14	23.5	20.1	
50	"	11	17.5	18.2	22.9
51	"	13	31.0	28.6	
52	300	13	14.5	13.4	
53	"	13	25.0	23.1	16.9
54	"	15	18.0	14.4	
55	600	[illegible]	10.0	10.2	
56	"	12	15.0	15.0	13.4
57	"	11	13.0	14.2	
58	1200	12	5.0	5.0	
59	"	13	7.0	6.5	6.3*
60	"	12	7.5	7.5	
	Least significant difference at 5%			7.[illegible]	

* Significantly different at 5%.

FIGURE 3. SUDAN GRASS GROWTH AS IT IS AFFECTED BY LEAD ARSENATE MIXED WITH SOILS

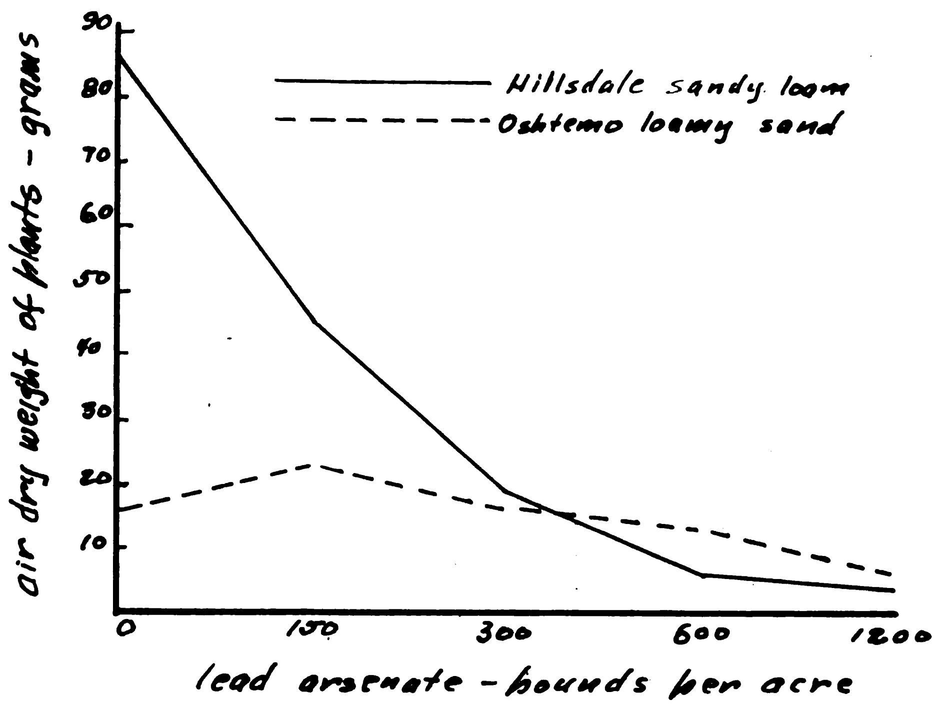
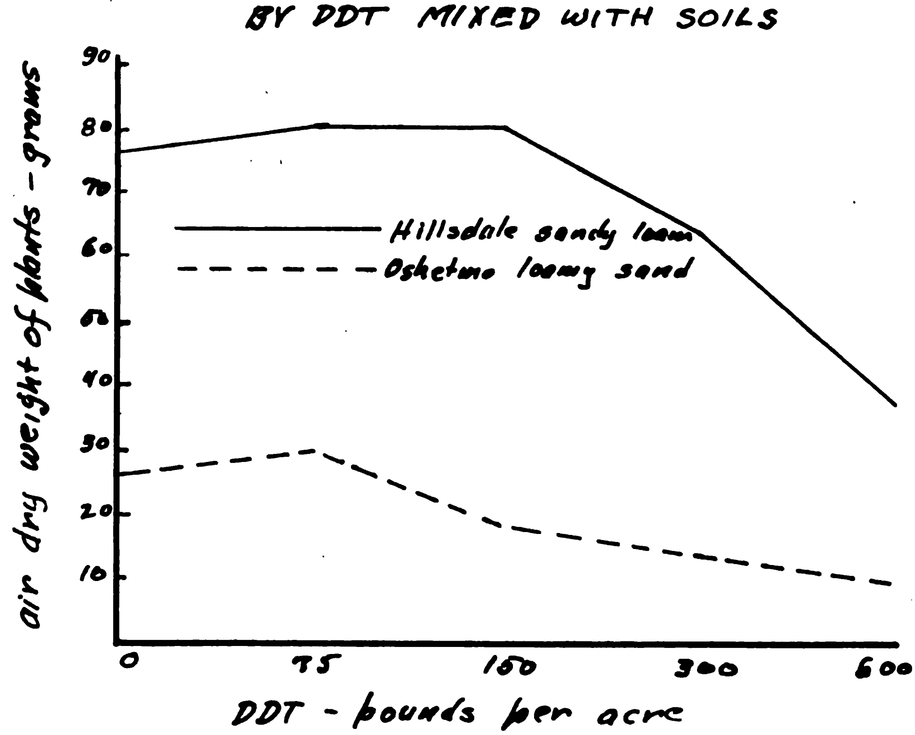


FIGURE 4. SUDAN GRASS GROWTH AS IT IS AFFECTED BY DDT MIXED WITH SOILS



growth. Both were supplied with what was thought to be adequate amounts of nutrients, yet the plant growth was much greater, as an average, on the Hillsdale sandy loam than on the Oshtemo loamy sand. Second, there was a much wider range of toxicity response to lead arsenate with the Hillsdale than with the Oshtemo. No arsenic resulted in five times more growth and 1200 pounds lead arsenate in only one half as much growth on the Hillsdale as on the Oshtemo. There appeared to be no correlation between soil reaction and arsenic toxicity. The slight difference found in these soils, Hillsdale pH 5.4 and Oshtemo pH 5.1, could hardly be suspected as causative.

The lower yields, in general, obtained on the sand could be attributed to the lower general productivity of this particular soil.

Possibly the decreased range of growth depression on the loamy sand resulted from a greater rate of translocation of active arsenic by solution or elutriation from the upper to the lower portion of the soil mass, the watering having been from the top. This would be in agreement with Williams and Whetstone (23) who believe arsenic would be leached in acid sandy soils. The silt and clay, higher in proportion in the sandy loam, could have maintained a toxic concentration of active arsenic throughout its soil mass. It has been shown (9) that it is the more nearly water soluble fractions of arsenic that are toxic and that if roots can develop in areas free of active arsenic the plant growth will be more nearly normal (13). Greaves (9) also reports a wide variation between total and water soluble arsenic in various soils. This he attributes among other factors, to the "kind" of soil without suggesting more definitely the soil characteristics involved.

The susceptibility of Sudan grass to arsenic toxicity is not in agreement with Vincent (22) who includes Sudan grass among green manure crops recommended for reclaiming arsenic contaminated soils.

The slight increase in growth of Sudan grass on Oshtemo loamy sand, obtained with the first increment of lead arsenate, might be significant. Greaves (9) reports that bacterial action is stimulated at from 60 to 100 pounds of arsenic, though it is depressed at 600 pounds per acre. There could be an associated benefit to plant growth.

Depression of Sudan grass growth was observed from emergence on, and was greater on the Hillsdale sandy loam than on the Oshtemo loamy sand series. The appearance of the Sudan grass showed little difference other than a generally diminished growth (Plates VII and VIII.) There was a browning of the roots near the soil surface but since it was more or less uniform in all treatments, and the control, this was thought to be normal. Root development appeared to parallel that of the tops.

<u>DDT - Sudan grass.</u> As is shown in Table V and Figure 4, DDT apparently had a significantly depressing effect on the growth of Sudan grass on Hillsdale sandy loam at between 300 and 600 pounds per acre and on Oshtemo loamy sand at 150 pounds per acre. At lower

PLATE VII

SUDAN GRASS GROWING IN HILLSDALE SANDY LOAM TREATED WITH VARYING CONCENTRATIONS OF LEAD ARSENATE. LEFT TO RIGHT: 0, 150, 300, 600, AND 1200 POUNDS PER ACRE

PLATE VIII

SUDAN GRASS GROWING IN OSHTEMO LOAMY SAND TREATED WITH VARYING CONCENTRATIONS OF LEAD ARSENATE. LEFT TO RIGHT: 0, 150, 300, 600 AND 1200 POUNDS PER ACRE

TABLE V

EFFECT OF DDT MIXED WITH HILLSDALE SANDY LOAM AND OSHTEMO LOAMY SAND ON GROWTH OF SUDAN GRASS

Pot Number	DDT Per Acre	Plants Harvested	Air Dry Weight of Plants: Total	Air Dry Weight of Plants: Adjusted to 12 plants	Air Dry Weight of Plants: Treatment Average
	pounds		grams	grams	grams
		Hillsdale sandy loam			
1	0	12	[illegible]	72.0	
2	"	12	90.5	90.5	80.4
3	"	11	[illegible]	[illegible]	
4	75	12	[illegible]	[illegible]	
5	"	12	71.0	71.0	82.7
6	"	12	92.0	92.0	
7	150	12	[illegible]	83.0	
8	"	13	[illegible]	77.0	80.[illegible]
9	"	12	[illegible]	[illegible]	
10	300	12	69.5	69.5	
11	"	13	48.5	44.7	63.5*
12	"	11	70.0	76.3	
13	600	[illegible]	36.0	[illegible]	
14	"	13	31.5	29.1	36.9*
15	"	12	42.5	42.5	
		Least significant difference at 5% 15.8			
		Oshtemo loamy sand			
31	0	12	28.5	28.5	
32	"	14	22.0	18.9	26.8
33	"	12	33.0	33.0	
34	75	15	42.0	33.6	
35	"	12	32.0	32.0	29.4
36	"	12	22.5	22.5	
37	150	13	22.0	20.3	
38	"	12	19.0	19.0	18.9*
39	"	12	17.5	17.5	
40	300	12	25.5	25.5	
41	"	12	10.5	10.5	17.1*
42	"	13	16.5	15.3	
43	600	13	13.0	12.0	
44	"	14	11.5	9.0	9.[illegible]*
45	"	12	6.0	6.0	
		Least significant difference at 5% 3.[illegible]			

* Significantly different at 5%.

concentrations the depression did not occur. The curve trends in Figure 4 and the plant appearances in Plates IX and X suggest a slight stimulatory effect. This would be in keeping with the claim of Chapman and Allen (5) who credit DDT with being a hormone-like plant-growth promoter up to certain critical concentrations, varying among plant species, above which it becomes a depressant.

Goldsworthy and Dunegan (8) found the growth of strawberry plants depressed at 100 pounds per acre technical DDT while the pure DDT showed no growth depression up to 400 pounds. These same investigators claim there are unknown impurities in DDT responsible for much of the plant growth suppression.

In the DDT series it was 25 days after planting before there was any growth difference which could be interpreted as indicating treatment effects. At this time, December 15, there appeared to be a depression of growth at 600 pounds per acre, the maximum concentration.

On January 2, after the November 20 planting, there appeared to be a definite stimulation of growth on the Hillsdale sandy loam series at the two lower DDT concentrations; 75 and 150 pounds per acre. No such stimulation could be visually recognized on the Oshtemo loamy sand series. Final appearance is shown in Plate X.

<u>Lead arsenate - Soybeans.</u> Lead arsenate mixed with Hillsdale sandy loam significantly depressed soybean growth, as shown in Table VI, on Hillsdale sandy loam at the 600 pounds per acre

PLATE IX

SUDAN GRASS GROWING IN HILLSDALE SANDY LOAM TREATED WITH VARYING CONCENTRATIONS OF DDT. LEFT TO RIGHT: 0, 75, 150, 300, AND 600 POUNDS PER ACRE

PLATE X

SUDAN GRASS GROWING IN OSHTEMO LOAMY SAND TREATED WITH VARYING CONCENTRATIONS OF DDT. LEFT TO RIGHT: 0, 75, 150, 300, AND 600 POUNDS PER ACRE

TABLE VI

EFFECT OF LEAD ARSENATE MIXED WITH HILLSDALE SANDY LOAM AND OSHTEMO LOAMY SAND ON GROWTH OF SOYBEANS PLANTS AND ROOT NODULATION

Pot Number	Lead Arsenate Per Acre	Air Dry Weight of Plants: Per Pot	Air Dry Weight of Plants: Average	Nodulation of Roots: Per Pot	Nodulation of Roots: Average	Nodulation of Roots: Secondary Roots
	pounds	grams	grams			
		Hillsdale sandy loam				
16	0	73		40		0
17	"	67	[illegible]	67?	[illegible]	0
18	"	59		64		1
19	150	63		52		0
20	"	76	74	66	58	0
21	"	83		55		0
22	300	[illegible]		[illegible]		[illegible]
23	"	[illegible]	[illegible]	45	[illegible]*	[illegible]
24	"	53		30		[illegible]
25	600	47?		4		[illegible]
26	"	50	44*	5	11*	5
27	"	42?		23		1
28	1200	42?		2		0
29	"	41	44*	21	8*	2
30	"	35		1		8
Least sig. dif. at 5%			[illegible]		12.7?	
		Oshtemo loamy sand				
46	0	73		44		0
47	"	83	81	49	52?	0
48	"	87?		63		1?
49	150	[illegible]		47		0
50	"	[illegible]	76?	57	[illegible]	0
51	"	79?		57?		0
52	300	68?		33?		0
53	"	62	66*	44	37?	0
54	"	79?		29		0
55	600	55		25		0
56	"	68	62*	55?	15?	[illegible]
57	"	64		42?		0
58	1200	51		33		0
59	"	54	52*	39?	35	0
60	"	52?		33		0
Least sig. dif. at 5%			[illegible]		[illegible]	

* Significantly different at 5%.

concentration and on Oshtemo loamy sand at 300 pounds per acre. The lighter textured soil, in the case of Sudan grass too, showed significant growth depression at the lower lead arsenate concentrations. This agrees with the finding of others (18,22,23) that arsenic is more toxic, or toxic at lower concentrations, in coarser textured soils.

Nodule numbers were decreased, following the trend of yield depression shown in Figures 5 and 6. However the effect on nodulation in the Oshtemo loamy sand series is not significant at the five percent level. It is difficult to explain why plant growth, shown in Table VI, was greater on the Oshtemo loamy sand than on the Hillsdale sandy loam. The opposite was the case with Sudan grass (Table IV). Another trend which is different on the two soils is that of nodulation. As the lead arsenate concentration was increased the depression of plant growth was accompanied by an even greater depression in nodulation on the Hillsdale sandy loam than on the Oshtemo loamy sand.

The same explanation might hold which was suggested in the preceeding discussion of the Sudan grass growth data. If the concentration of active arsenic in the surface two or three inches had been reduced, by translocation action of water, to a greater degree in the sand than in the sandy loam, there could be two reasons for a difference in growth suppression. First, as in the case of Sudan grass, there would have been left an area more free of arsenic for root activity. Secondly, t at area in which nodulation is naturally

FIGURE 5. SOYBEAN GROWTH AND NODULATION AS AFFECTED BY MIXING LEAD ARSENATE WITH HILLSDALE SANDY LOAM

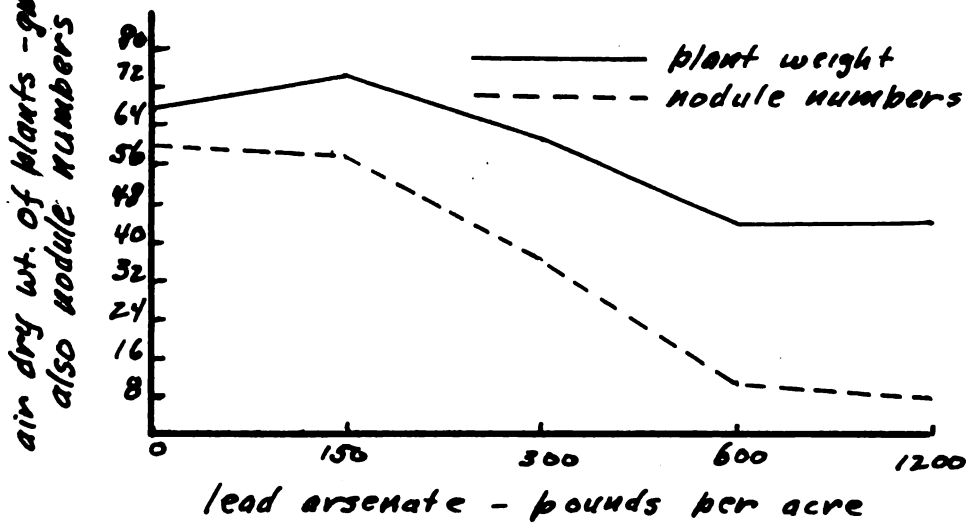
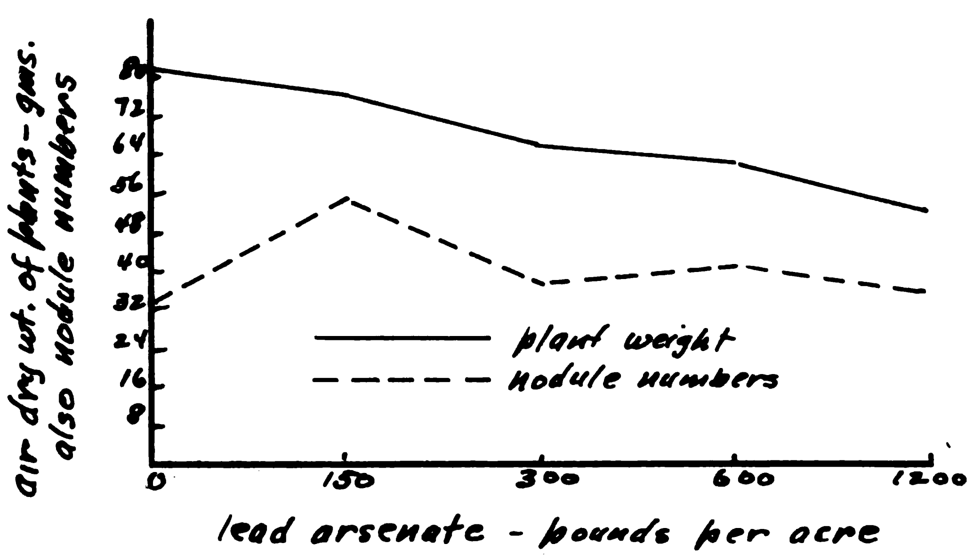


FIGURE 6. SOYBEAN GROWTH AND NODULATION AS AFFECTED BY MIXING DDT WITH OSHTEMO LOAMY SAND



more active would be less contaminated. If this condition favored the action of Rhizobia it would tend to affect the relative supply of nitrogen on the treated soils, favoring the Oshtemo loamy sand. (In all pots there were few nodules located more than an inch from the root base.)

The high percentage of plants having nodule-barren roots in the Hillsdale sandy loam series, at the 600 and 1200 pounds per acre concentrations, would tend to substantiate this view. Greaves (9), working with nitrifying and ammonifying bacteria found these groups to exist, without entirely stopping activity, at concentrations of as much as 82 parts per million, water soluble As_2O_3, and that nitrification and ammonification proceeded at a high rate at 50 parts per million. No record was found of experiments with arsenic involving the specific bacterial group, Rhizobia.

DDT - Soybeans. The same plant growth trends were exhibited with DDT treatments as with lead arsenate as shown by data in Table VII and in Figures 7 and 8. Plant growth was decreased with increasing concentrations of DDT. Growth was generally greater on the lighter, Oshtemo loamy sand. The incidence of plants with nodule-barren roots was significant at the 300 and 600 pounds per acre concentrations.

Neither the data nor observations during growth indicated any of the stimulatory effect exhibited by the Sudan grass - DDT phase of this investigation. That nodulation was stimulated at the lowest

TABLE VII

EFFECT OF DDT MIXED WITH HILLSDALE SANDY LOAM AND OSHTEMO LOAMY SAND ON GROWTH OF SOYBEANS AND ROOT NODULATION

		Air Dry Weight of Plants		Nodulation of Roots		
Pot Number	DDT Per Acre	Total 8 Plants	Treatment Average	Total 8 Plants	Treatment Average	Barren Roots
	pounds	grams	grams	number	number	number
		Hillsdale sandy loam				
1	0	73		55		0
2	"	67	68.0	56	52.0	0
3	"	64		45		0
4	75	55		73		0
5	"	70	62.3	52	67.7	0
6	"	62		78		0
7	150	54		63		0
8	"	54	53.3*	23	48.7	1
9	"	52		60		2
10	300	37		26		3
11	"	28	34.0*	55	32.7	3
12	"	37		17		2
13	600	43		35		3
14	"	33	33.0*	35	33.0	3
15	"	23		29		4
	Least sig. dif. at 5%		11.65	Dif. not significant at 5%		
		Oshtemo loamy sand				
31	0	76		57		0
32	"	82	79.7	57	61.0	0
33	"	81		69		0
34	75	74		69		0
35	"	73	70.7*	64	61.6	0
36	"	65		52		0
37	150	54		92		0
38	"	64	58.3*	63	71.0	0
39	"	57		58		0
40	300	48		89		0
41	"	48	48.0*	88	83.3	0
42	"	48		73		0
43	600	42		59		0
44	"	33	34.3	80	61.3	0
45	"	28		45		0
	Least sig. dif. at 5%		8.53	Dif. not significant at 5%		

* Significantly different at 5%.

FIGURE 7. SOYBEAN GROWTH AND NODULATION AS AFFECTED BY MIXING DDT WITH HILLSDALE SANDY LOAM

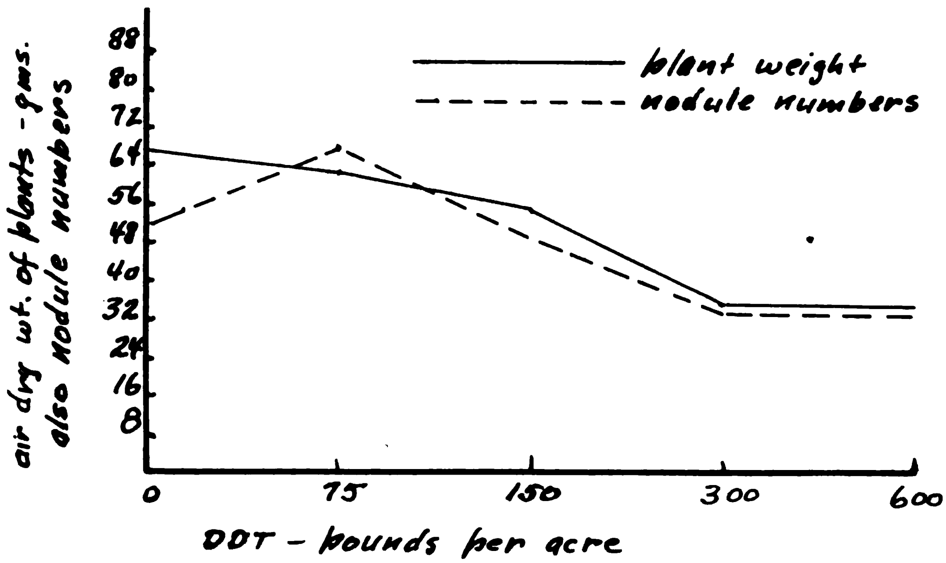
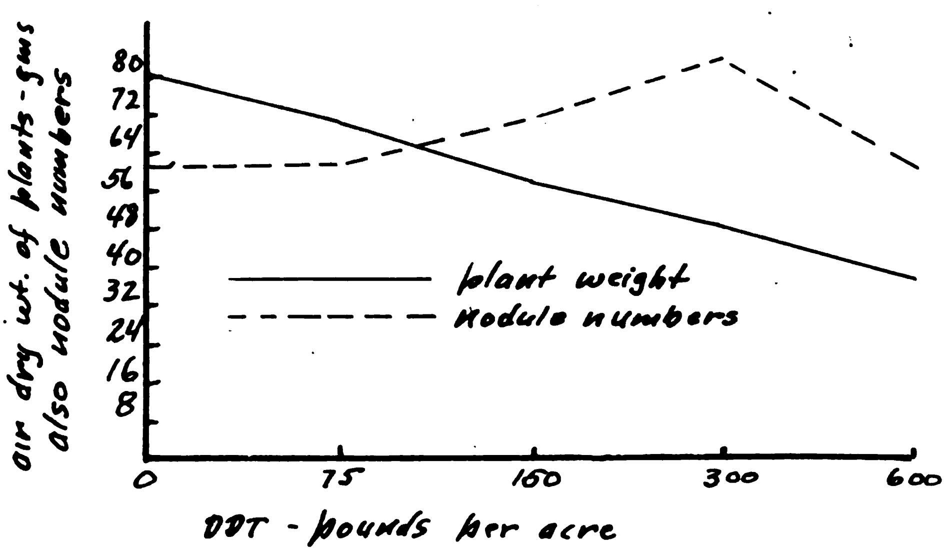


FIGURE 8. SOYBEAN GROWTH AND NODULATION AS AFFECTED BY MIXING DDT WITH OSHTEMO LOAMY SAND



concentration for the Hillsdale and at the first three increments for the Oshtemo, is indicated in Figure 5.

The postulation of translocation of toxic materials to lower portions of the soil mass, made in the case of lead arsenate treatments, would not be justified in this case, unless it can be shown that the toxic material is water-soluble or otherwise mobile. Foster (7) applied DDT to soil under field conditions in amounts up to 400 pounds per acre and, after four years, found by tests that very little had been lost. There is again the possibility that impurities associated with technical DDT could be both toxic and soluble permitting more rapid translocation from the surface region of the coarser textured Oshtemo loamy sand than the Hillsdale sandy loam.

Work of many investigators (1,14,20,24) indicates that soil bacteria in general have a high tolerance for DDT, and little suppressive effect on Rhizobia could be expected. Appleman (1) worked specifically with Rhizobia.

SUMMARY AND CONCLUSIONS

Hillsdale sandy loam soil, from which an old apple orchard had been removed, was used in greenhouse studies to determine the effects of the accumulation of spray residues on plant growth. Following removal of the trees, crops including strawberries followed by Sudan grass, had shown suppressed growth in a pattern which coincided with former tree locations. The soil used in these studies contained 220 parts per million arsenic (As_2O_3). A normal, arsenic-free soil was mixed with the orchard soil at varying percentages in two series; fertilized and unfertilized. The normal soil used for this purpose was Oshtemo loamy sand, coarser in texture and lower in fertility.

Growth of navy beans was significantly improved through the addition of normal soil starting at the 50 percent level on the unfertilized, and at the first increment of normal soil, 25 percent, on the fertilized series. The critical level for growth suppression was indicated as being between 360 and 720 pounds total As_2O_3 per acre on the fertilized series. Such a calculation could not be made on the unfertilized series because of the strong secondary influence of low inherent productivity of the normal soil.

Symptoms of toxicity were variable but the most common was a watery breakdown and subsequent drying of the leaves while retaining their green color. Emergence and early growth was not noticeably affected.

Tomato plants in the same series of soil mixtures, without additional fertilization, gave no indication of growth suppression due to the arsenic in the orchard soil; the yields apparently followed the fertility pattern as influenced by the contrasting fertility levels of the two soils. Some single pot treatments, intended only as observational tests, did indicate a suppression of tomato growth when lead arsenate had been mixed with the normal soil at the rate of 3500 pounds per acre, and perhaps significantly so at the 1750 and 875 pound levels also. These rates correspond to 1000, 500 and 250 pounds As_2O_3 respectively. This indicated a possibly higher toxicity with freshly applied lead arsenate. Perhaps a greater fixation of arsenic occurred when it accumulated over a period of time under field conditions.

Perhaps tomatoes are a crop sufficiently tolerant to arsenic to be utilized economically on arsenic contaminated soils. According to McLean(16) the fruit grown on such soils would not contain sufficient quantities of arsenic to render it unsafe for human consumption.

Lead arsenate, mixed with fertilized Hillsdale sandy loam and Oshtemo loamy sand in the laboratory in concentrations amounting to 150, 300, 600, and 1200 pounds per acre, depressed growth of Sudan grass markedly at all rates on Hillsdale sandy loam, and significantly on the Oshtemo loamy sand at only the 1200 pound rate. There was reason to suspect that there had been a translocation or leaching through watering of the more soluble toxically-active fraction of the arsenic in the coarser textured Oshtemo loamy sand, leaving areas relatively less toxic in the upper part of the soil mass.

The addition of DDT to these soils at rates of 75, 150, 300 and 600 pounds (50 percent commercial) per acre depressed Sudan grass growth on Hillsdale sandy loam at the 300 and 600 pound per acre rates. There appeared to be a slight stimulation in plant growth at the lower rates of application. There was little depression of Sudan grass growth from DDT on the Oshtemo loamy sand indicating, as in the case with lead arsenate, the possibility of translocation of mobile toxic fractions from the upper layers in the coarser textured soil. Some investigators claim that technical DDT does contain toxic impurities.

Soybeans, following the Sudan grass, without additional soil or treatment were depressed in growth by both lead arsenate and DDT on both soils, but to a greater degree on the Hillsdale sandy loam. Nodulation was depressed by both lead arsenate and DDT on the Hillsdale but neither depressed nodulation on the Oshtemo. There was again evidence that some soluble or mobile toxic impurity in the commercial DDT is responsible for suppression of growth and root nodulation.

The accumulation of spray residues in soil should be a matter of concern to the grower of crops which must be sprayed. Lead arsenate does accumulate in soil in amounts which prove toxic to some plants. The same may be true of DDT and other more recently introduced pesticides. Where a choice of spray materials can be made, the residual effect on soil should be considered. Soils that have been subjected to contamination should be tested either chemically or biologically and, if there are harmful effects, proven corrective measures should be undertaken. These measures might include crop selection, liming, fertilization, addition of organic matter and use of specific counteractants or inactivators.

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