THE USE OF WOODCHIPS AND OTHER WOOD FRAGMENTS AS SOIL AMENDMENTS

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The fact that more than half of Connecticut's land area is in woodlots and forests means a large total annual production of wood, even though the production per acre is low. Much of this wood consists of poorly shaped and diseased stems, weed species, and other material of low value. Proper woodland management calls for periodic weeding and thinning. Little of the material obtained from these practices has commercial value.

This low-grade wood can be (a) left on the ground where it eventually decays but presents a fire hazard for several years; or

(b) it can be piled and burned, thus involving considerable labor and also causing somewhat of a fire hazard; or

(c) it can be chipped and let lay in the woods, which greatly reduces the fire hazard; or

(d) it can be chipped and used for improving soils under cultivation.

The last named plan would seem to have special merit, for a convenient source of organic matter for farm soils would provide another incentive for improving woodlot and forest land. The question is, "How effective are woodchips as a soil improver?" To obtain the answer, experiments were initiated at this Station in 1949.

Although some aspects of the work have been reported previously (11, 12, 13), the present bulletin is a complete report on the project.

Historical Aspects

Some farmers and gardeners have tried applying sawdust or shavings to their soils, frequently with disappointing and sometimes disastrous results. Others have used them for many years and found them beneficial, particularly when applied as a mulch and eventually worked into the soil. As is usually the case, the failures make a greater impression than the successes. Hence, it is generally believed that wood waste fragments in fresh form are toxic to plants, and that they increase the acidity of the soil. Also, there are differences of opinion as to the desirability of using manure which contains sawdust, shavings, or chips as bedding material.

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[1]Department of Soils. The author is indebted to D. B. Downs, Wm. Blatchley, Ann Chandl, Ruth Galinat, James George, R. M. Hanna, J. P. Hollis, and M. Wang for assistance in conducting these experiments.

The literature available prior to the start of these experiments (1949), refers mostly to the use of these materials as a surface mulch, rather than as something to incorporate into the soil. Very few references dealt with chips as contrasted with sawdust or shavings. This earlier work was adequately reviewed by Roberts and Stephenson (17) and Allison and Anderson (2). In brief, the data showed that sawdust when applied as a mulch generally was beneficial to the soil and to plant growth. When incorporated into the soil, its chief effect was temporarily to deplete the soil of available nitrogen. Among the tree species used, only walnut and cedar appeared to have toxic effects.

Unless sufficient extra nitrogen was provided, yields of the first crop following application of woodchips or sawdust were reduced, but the second crop usually benefited from the treatment. Inoculated legumes suffered no reduction in growth. Non-symbiotic fixation of nitrogen was not affected, nor was the reaction of the soil appreciably changed.

Waksman (21) has shown that humus is high in lignin content; thus organic matter containing large amounts of lignin is quite stable in the soil (15). Wood contains 42 to 54 per cent lignin (5) as compared with 11 per cent for corn stalks and 14 per cent for rye straw (19). Therefore, wood waste should be an effective material for increasing the humus content of the soil.

The paucity of experimentation prior to 1949 on the value of woodchips for soil improvement and the increasing interest in the utilization of such material made it advisable that further studies be made. Apparently, the need for additional information was felt by others at about the same time, for the literature on the subject has increased markedly since 1949, as is evident from the list of publications cited at the end of this bulletin.

Experimental

The experimental work reported in this bulletin was carried on under the following general headings:

A. Greenhouse pot cultures in two-gallon glazed pots.

Experiment I. Seed germination and root injury data obtained on Cheshire loam and Merrimac sandy loam in the 1949 growing season.

Experiment Ia. Plant growth and soil data obtained during cropping with six successive crops (beets and spinach) on the same two soils, 1949-51.

Experiment Ib. Treatments in Expt. Ia were revised slightly and two more crops grown in the same two soils, 1951-52.

Experiment II. Dealt primarily with composted chips on Hartford loamy sand. There were four successive crops, 1950-52.

B. Outdoor soil frames containing Cheshire loam.

Experiment III. Covering four successive crops (three of beets and one of snapdragons), 1950-53.

Experiment IIIa. Treatments were revised slightly and one more beet crop grown, 1954.

C. Field plot work.

Experiment IV. Covering three corn crops on Cheshire loam at Mt. Carmel Farm, 1950, '51 and '53.

Experiment IVa. At Peoples State Forest on Merrimac sandy loam in which coniferous tree seedlings were grown two years from seed; 1951-53.

Experiment IVb. Budded apple trees in a commercial nursery on Hartford sandy loam, 1952-54.

The general procedure was to incorporate woodchips into the soil, then grow successive crops without further additions of chips. In some cases extra nitrogen was applied. Yields of the crop were recorded and the soils quick-tested from time to time. After a year or more, quantitative physical and chemical analyses were made on the soil to determine what improvement, if any, had been brought about by the treatments.

METHODS OF ANALYSES

Quick tests were made by the Morgan method[1]; *soil reaction* was determined in a thin paste soil-water suspension by means of a glass electrode pH meter; *total nitrogen* by the Gunning method; *organic carbon* by the wet combustion method of Schollenberger[2], and *cation exchange capacity* according to Chandler's[3] barium acetate-electrometric titration method.

The physical tests included *moisture equivalent* by the centrifuge method of Veihmeyer[4]; *field moisture capacity* was determined by sampling the soil within 48 hours of a very heavy rain; *bulk density* by obtaining the dry weights of 250 ml core samples in brass cylinders, taken with a soil core sampler, using a hammer on a block of wood as a buffer, rather than the tripod or wheel-mounted support described by Swanson[5]; *water-holding capacity* by soaking the core soil samples overnight, then determining the moisture remaining after the soils had drained 24 hours on a thick mat of newspapers; total *pore space, capillary* and *non-capillary* capacity were determined and calculated by standard methods[6,7]; and *aggregate analysis* by a modification of the Yoder method as used by Swanson, Hanna, and deRoo[8].

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1 Conn. Agr. Expt. Sta. Bul. 541, 1950.

2 Soil Science 40:311-320, 1935.

3 Jour. Agr. Res. 59:491-506, 1939.

4 Proc. First Internatl. Cong. Soil Sci. Washington 1:512-534, 1927.

5 Agronomy J. 42:447-451, 1950.

6 Jour. Am. Soc. Agron, 33:1003-1008, 1941.

7 Baver, L. D. Soil Physics. John Wiley and Sons, New York, 1948.

8 Soil Science 79:15-24, 1955.

9 The chips used in these experiments were obtained through the courtesy of Robert A. Schrack, Forestry Specialist, Soil Conservation Service, East Greenwich, R.I.

GREENHOUSE POT CULTURES

Expts. I, Ia and Ib — Use of Fresh Chips[9]

In the initial work (Expts. I and Ia) fresh oak-hickory chips of variable sizes (as they came from the chipper) were added to topsoil (plow layer) of a Cheshire loam of low fertility at five rates, viz., 0, 5, 10, 20 and 40 tons of dry matter per acre (Table 1). To assist in overcoming nitrogen deficiency, ammonium nitrate was applied at the rate of one-half pound of N for every 100 pounds of dry organic matter added. All pots received a standard treatment of 5-10-10 fertilizer and ground limestone at rates equivalent to 2500 and 3000 pounds per acre, respectively.

To compare kinds of chips and rates of nitrogen, a series of pots was included in which oak-hickory, aspen-gray birch, and red and white pine chips[1] were applied to the same kind of soil at 10 tons per acre, with three levels of extra N, i.e., none, one-half pound, and one pound of N per 100 pounds of dry organic matter. In these cases the limestone applications were 2500, 3000 and 3500 pounds per acre, respectively. Another series consisted of a 10-ton application of oak-hickory chips to topsoil of Merrimac sandy loam, with three levels of N as above.

In all cases, the chips, fertilizer, and lime were thoroughly mixed with the soil. Chips and extra nitrogen were applied only once — at the initiation of the study.

In the beginning there were six replicates of all treatments. Three of these were used to test the effect of chips on seed germination, growth of lettuce, and root injury of lettuce and radishes (Expt. I). This portion of the work was conducted by J. P. Hollis of the Department of Plant Pathology during the spring and summer of 1949 (Table 1).

The remaining three replicates (Expt. Ia) were cropped to beets and spinach in 1949. In 1950, the pots used for the germination work in Expt. I were incorporated into Experiment Ia, and cropping of the six replicates continued (Table 2). In the fall of 1950, the soil from the six replicates was mixed and repotted in triplicate, discarding the excess, and the fifth and sixth crops grown.

In the summer of 1951, following the sixth successive crop, the treatments were revised by combining the soils which had received the three N levels, adjusting all treatments to pH 6.0 as nearly as possible, refertilizing with a low nitrogen-high potash mixture, and repotting in triplicate. Also, the 5-T rate of oak-hickory chips was dropped. This phase is designated as Expt. Ib (Tables 3 and 4).

Results

Expt. I Germination, root injury and seedling growth[2]. Data taken 10 to 14 days after sowing the seed were obtained on four successive sowings as follows:

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[1]Throughout this bulletin, abbreviations of these species where used are O-H, A-GB and Pine, respectively.

[2]Based on a report prepared by J. P. Hollis.

Sowing	*Date*	*Crop*	*Data obtained*
1st	April 5	Radishes and lettuce	Root injury
2nd	April 25	Lettuce	Seedling growth
3rd	May 18	Lettuce	Germination and root injury
4th	July 19	Lettuce	Germination

Injury to the roots was determined on 20 seedlings in each treatment, using the method of Horsfall and Barrett (10). The investigation showed that there was no injury on the radish seedlings; on the lettuce roots there were reddish-brown lesions believed to be caused by a fungus. The symptoms were found in all treatments, thus indicating that the decomposing organic matter had no direct toxic effect on the roots. It was observed that root injury was more severe in the Merrimac than in the Cheshire soil. No reason for this difference between soils is suggested.

Seedling-growth observations, made only in the second sowing, showed that the plants growing in soil with the 20- and 40-T/A rates of oak-hickory chips and the 10-T/A rate of aspen-gray birch chips were appreciably stunted. All others were normal.

TABLE 1. EFFECT OF WOODCHIPS ON GERMINATION OF LETTUCE SEED IN GREENHOUSE POT EXPERIMENTS (EXPT. I)
Per cent germination; averages of 3 replicates

	Cheshire loam								Merrimac sandy loam	
Extra N, %	Check 0	Oak-hickory T/A 5	10	20	40	A-GB 10 T/A	Pine 10 T/A	Av. 10 T/A rate only	Check 0	O-H 10 T/A
Third sowing May, 1949										
0	51	....	68	....	....	71	65	64	62	65
½	30	59	67	69	71	68	37	50	....	74
1	24	....	48	....	....	77	24	43	....	58
Av.	35	....	61	....	....	72	42	....	....	66
Rel.	100	....	174	....	....	206	121	....	....	....
Fourth sowing July, 1949										
0	70	....	93	....	....	85	83	83	72	95
½	56	66	80	57	60	88	56	70	....	79
1	59	....	55	....	....	47	37	49	....	39
Av.	61	....	76	....	....	74	59	....	....	75
Rel.	100	....	123	....	....	120	95	....	....	....

Significance of differences,[1] Cheshire loam only	3rd sowing	4th sowing
O-H chips, ½% N		
Check vs. chips	HS	ns
Between rates	ns	ns
Comparison of kinds of chips at 10 T/A each		
Check vs. chips	HS	ns
Between kinds of chips	HS	ns
Comparison of rates of extra N		
None vs. ½%	S	S
None vs. 1%	HS	HS
½% vs. 1%	ns	HS

[1] Analysis of variance. HS = 1% point; S = 5% point; ns = not significant.

Data on lettuce seed germination are given in Table 1. In the third sowing in Cheshire loam there was a highly significant increase in the germination rate as a result of the oak-hickory chips treatment, but differences between rates of application were not significant. Comparing kinds of chips, aspen-gray birch resulted in the highest germination followed by oak-hickory, then pine, with the check lowest. These differences were highly significant.

As for the effect of extra N, increasing the rate resulted in a decrease in germination, the differences being significant.

On the Merrimac soil, germination differences in the third sowing were not significant.

In the fourth sowing, none of the increases for chips were significant, but the unfavorable influence of extra N was either significant or highly significant. A similar situation prevailed in the Merrimac sandy loam trials.

What is the explanation for these findings on germination? Other workers (1, 14) have found that fertilizers adversely affect germination, chiefly as a result of the increased concentration of total soluble salts in the soil. Confirmation of these findings was obtained in a petri dish experiment in this laboratory in which progressive increases in concentration of fertilizer, manure, or digested sewage sludge decreased germination (Figure 1). Thus it appears that the favorable effect of chips was due to the accompanying reduction in nitrate content by the cellulose-decomposing micro-organisms. Conversely, increasing the amount of extra N caused an increase in salt concentration and thus reduced germination.

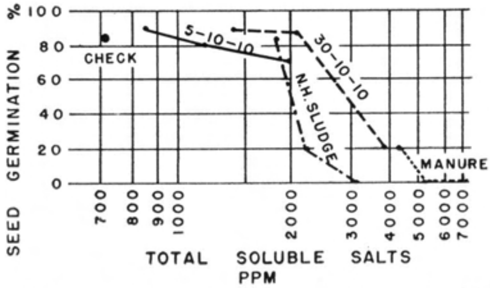

Figure 1. Germination of lettuce seed in relation to total soluble salt content of the soil as a result of three levels of 5-10-10 and 30-10-10 fertilizers, manure (commercial dried), and New Haven digested sewage sludge. Expt. I.

Rates of application, left to right:

	Lbs per acre		
5-10-10	667	2000	6000
30-10-10	667	2000	6000

	Tons per acre (dry)			*Per cent of soil by volume*		
Manure	35	70	105	11	22	33
Sewage sludge	28	56	84	11	22	33

In the fourth sowing the lessened beneficial effect of chips on germination indicated that the initial period of maximum utilization of nitrates by the bacteria had passed. But the bad effects of extra N persisted, seemingly in even greater degree.

Expt. Ia Plant Growth. Growth of five of the six crops, in terms of fresh or dry weights of the plants when harvested, are given in Table 2. Figure 2 shows the yields of the 1st, 3rd, 4th and 6th crops.

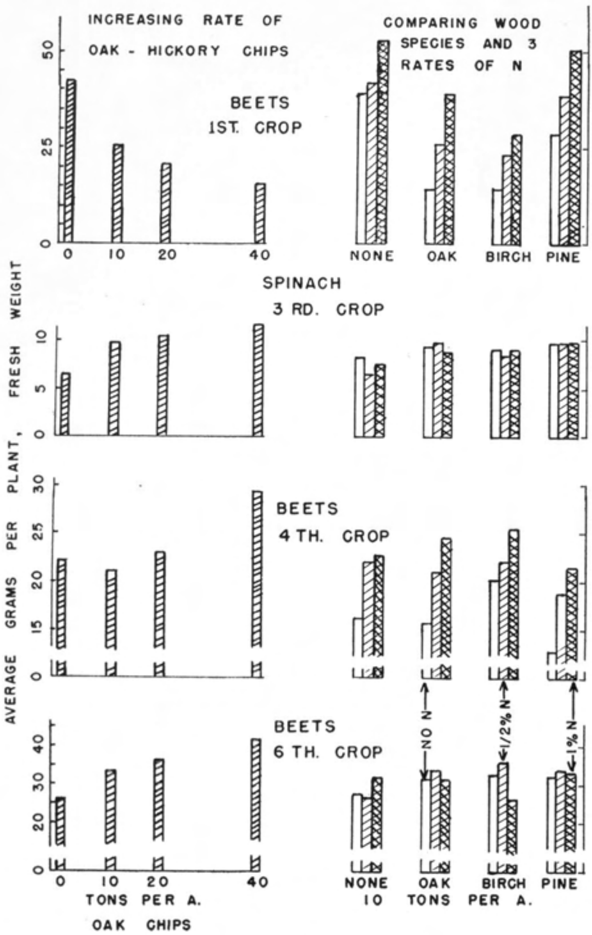

Figure 2. Effect of chips on beets and spinach growing on Cheshire loam in greenhouse pots. Left column, increasing application rate of oak-hickory chips; right column, comparison of kinds of chips and three application rates of extra N. (Chips and extra N applied at start only.)

Open bars = no extra N; angle hatching = 10 lbs N per T dry chips (½%); cross hatching = 20 lbs N per ton dry chips (1%). Check soil (no chips) received same amount of N as others. Expt. Ia.

TABLE 2. YIELDS OF THE SIX SUCCESSIVE CROPS IN GREENHOUSE EXPT. Ia

	Cheshire loam							Merrimac sandy loam	
	Check	Oak-hickory T/A				A-GB	Pine	Check	O-H
Extra N, %[1]	0 (1)	5 (2)	10 (3)	20 (4)	40 (5)	10 T/A (6)	10 T/A (7)	0 (8)	10 T/A (9)
First crop, BEETS. Fresh weight entire plant; g/pot of 6 plants, average of 3 replicates. Mar.-June, 1949									
0	229	......	85	......	......	83	171	159	59
½	275	173	151	127	91	138	230	......	130
1	320	......	230	......	......	173	303	......	189
Fresh weight of roots only									
0	90	......	18	......	......	13	87	39	18
½	109	83	61	20	11	29	103	......	55
1	114	......	101	......	......	56	112	......	58
Second crop, SPINACH. Fresh weight, g/pot, average of 3 replicates, Aug.-Nov., 1949									
0	32.5	......	47.2	......	......	56.5	30.2	26.3	48.2
½	27.8	36.0	35.7	45.8	52.5	43.8	26.5	......	32.3
1	32.4	......	25.2	......	......	34.8	27.7	......	25.5
Third crop, SPINACH. Fresh weight, g/pot, average of 6 replicates, Jan.-Mar., 1950									
0	32.3	......	36.7	......	......	35.9	38.5	15.1	28.9
½	25.2	35.0	38.7	40.3	46.0	33.2	38.5	......	24.2
1	29.5	......	35.5	......	......	35.9	39.2	......	26.3
Fourth crop, BEETS. Fresh weight, entire plant, g/pot, average of 6 replicates, Mar.-June, 1950									
0	97	......	98	......	......	121	77	127	82
½	132	111	130	134	175	125	110	......	95
1	137	......	146	......	......	145	127	......	127
Fresh weight of roots only									
0	33	......	33	......	......	53	32	42	26
½	59	39	50	53	95	50	49	......	39
1	67	......	57	......	......	59	64	......	45
Sixth crop, BEETS. Fresh weight entire plant, g/pot, average of 3 replicates, Feb.-May, 1951									
0	165	......	191	......	......	195	189	167	159
½	159	186	200	217	252	226	199	......	140
1	200	......	190	......	......	155	197	......	165
Fresh weight of roots only									
0	65	......	78	......	......	85	78	48	78
½	77	95	90	93	98	93	90	......	61
1	78	......	87	......	......	56	87	......	56

[1]Applied only once — prior to the first crop.

Considering first the four rates of oak-hickory chips on Cheshire loam, it is seen that for the first crop, Figure 3, the amount of extra N added was obviously insufficient, resulting in a progressive decrease in growth with each increase in rate of chips application.

By the time the second crop (spinach) came along, decomposition of the chips had proceeded far enough to show a tendency to reverse the effect, although the increases given are not statistically significant. Yields of the third crop (again spinach) were significantly increased by the chips, ranging from 39 to 82 per cent. In the fourth crop (beets, Figure 4) only the 40-T rate produced increases over the check. There was evidence from the soil quick tests that the phosphorus and potash level had been allowed to drop too low. The high yields of the 40-T rate may have been due in part to release of available N and in part to better physical condition of the soil.

A winter crop of beets (fifth successive crop) was harvested early before beets had formed, and the results were too variable to show anything of value.

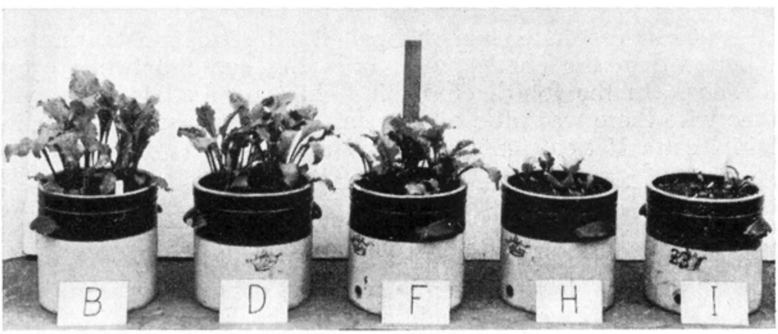

Figure 3. Effect of five levels of oak-hickory woodchips upon the growth of the first crop of table beets on Cheshire loam soil. B = no chips; D = 5 T/A; F = 10 T; H = 20 T; I = 40 T. All received extra nitrogen at the rate of ½ lb N per 100 lbs dry chips. (Treatment B received the same amount of N as treatment F.) Expt. Ia.

Figure 4. Effect of five levels of oak-hickory chips on the growth of the fourth successive crop (second beet crop) on this soil. Treatments are the same as indicated in Figure 3. Expt. Ia.

The sixth crop (beets) showed, as a result of the chips treatments, appreciable and highly significant increases in growth of the entire plant, ranging up to 59 per cent better than the checks. Yields of the beet roots were around 20 per cent greater than the checks, there being very little difference between the several rates of chip application.

Turning now to the three kinds of chips and the three rates of extra nitrogen, it is seen that in the first crop the poorest yields were obtained with the weed species chips (A-GB) and the best yields with pine (Table 2, cols. 3, 6, and 7). The well-known fact that weed species like aspen and gray birch rot faster and, by so doing, tie up more nitrogen than do the other species used, was substantiated by lower tests for nitrates and total soluble salts in the A-GB treated soil. The extra N was insufficient to meet the needs of the cellulose-decomposing organisms. On the other hand, pine decomposed so slowly as to require relatively little extra N. This is in agreement with Salomon's findings (18). He reported that pine contained 12 per cent more lignin than oak chips and this fact plus " . . . a greater concentration of resinous compounds and the less porous woody structure in pine are probably the major factors contributing to slower initial decomposition."

In the two succeeding spinach crops, all chips treatments were somewhat better than the checks, with little to choose between extra N applications. In the fourth crop, pine chips resulted in lower yields, but otherwise there was little difference. In most cases the benefits of the initial extra N treatments were still evident.

The sixth crop showed small and generally not significant increases of the three kinds of chips over the checks; and practically all effects of the original extra N treatments had disappeared.

With respect to Merrimac sandy loam, yields were generally lower than on the Cheshire soil, as would be expected. The 10-T rate of oak-hickory chips with 1 per cent N usually resulted in increased yields, although the increases were variable and for the most part, small. With less than 1 per cent extra N, chips were generally ineffectual in increasing yields.

Table 3. Yields of the Two Crops in Greenhouse (Expt. Ib)[1]
Fresh weight in grams per pot; average of 3 replicates in each case
(Only those in **bold** face show significance)

	Cheshire loam						Merrimac sandy loam	
	Check	Oak-hickory			A-GB	Pine	Check	10 T/A
	0	10 T/A	20 T/A	40 T/A	10 T/A	10 T/A	0	O-H
Spinach (Nov.-Dec., 1951)	19.6	18.5	19.9	**13.5**	**22.8**	**23.5**	16.6	**21.6**
Beets (Jan.-May, 1952)								
Whole plant	166	**222**	194	135	**179**	**174**	122	**176**
Beets only	35.7	66.3	42.7	14.3	38.7	43.3	18.0	33.0

[1]Essentially the 7th and 8th successive crops of Expt. Ia.

Expt. Ib Plant growth. Yields of the two crops of this experiment (actually equivalent to the 7th and 8th crops of Expt. Ia) are given in Table 3. The data show that spinach grown in Cheshire loam failed to respond favorably to oak-hickory chips, and the highest rate was definitely unfavorable. Both aspen-gray birch and pine chips resulted in increases. On the Merrimac, O-H chips increased growth by 30 per cent. No reasons for this variability in response could be found.

In the next and last crop (beets), 10-T of O-H chips produced appreciable increases on both soils, although the increases of the beet roots were shown by the T test to be not significant. The 40-T rate of O-H chips appeared to lower yields, and the A-GB and pine chip treatments generally were not significantly better than the checks.

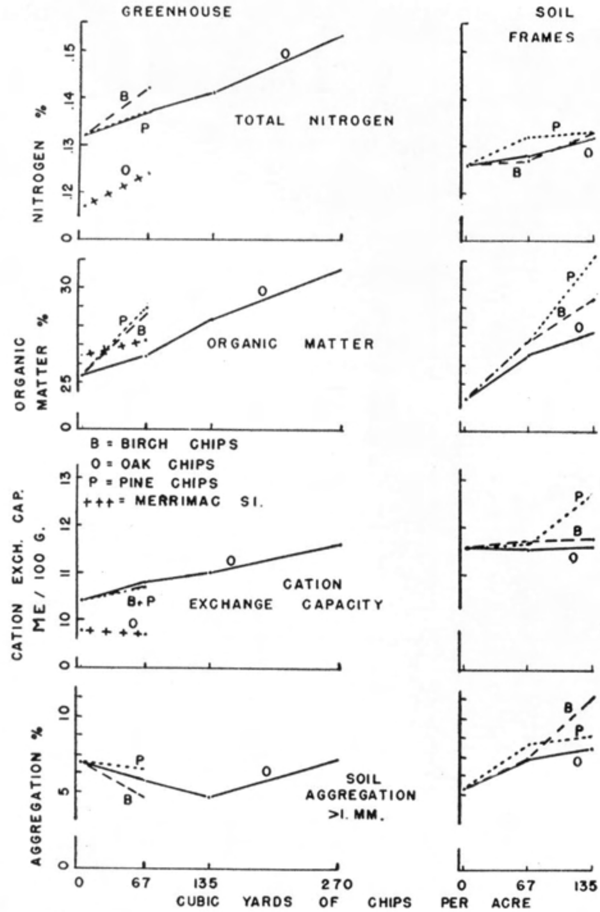

Figure 5. Effect of woodchips on properties of the soil. In the greenhouse: Cheshire loam and Merrimac sandy loam; in the soil frames: Cheshire loam. B = birch and aspen chips; O = oak and hickory chips; P = red and white pine chips. Expts. Ia, Ib and III.

Thus, this phase of the work showed that under the conditions of the experiment, chips tended to increase yields starting with the second crop and carrying through the sixth. In the two last crops, the benefits were much less certain and in some cases there appeared to be a reduction in yield.

Expts. Ia and Ib Soil properties. Periodic soil samplings made in the growing season of the *first* crop showed a slight increase in pH in both soils ranging from 0.2 to 0.4 pH units during the three months as result of the chips treatments.

The effects of the treatments on the pH and other soil properties *after* the first crop are shown in Table 4 and on the left column of Figure 5.

TABLE 4. EFFECT OF CHIPS ON PROPERTIES OF THE SOIL,[1] GREENHOUSE (EXPT. Ia AND Ib)

Soil Property	Sampling Date	Cheshire loam							Merrimac sandy loam	
			Oak-hickory				Asp-GB	Pine		
		Check	5 T/A	10 T/A	20 T/A	40 T/A	10 T/A	10 T/A	Check	O-H 10 T/A
pH	Sept '50	5.77	5.76	5.77	5.88	5.86	5.77	5.65	5.11	5.37
	June '51	6.00	......	5.82	......	......	5.85	5.66	5.82	5.92
Bulk density, g/ml	June '51	1.13	1.13	1.07	1.08	1.11	1.10	1.09	1.13	1.08
Water-holding capacity, %	June '51	29.6	27.7	30.1	27.7	30.6	28.8	29.3	26.2	33.9
Moisture eq., %	June '51	15.7	15.6	15.6	16.1	16.2	15.7	15.7	10.7	11.2
Total pore space, %	June '51	57.2	56.5	58.7	58.1	57.2	57.5	58.1	58.0	60.0
Capillary porosity, %	June '51	29.4	30.3	30.7	31.2	36.9	38.0	38.0	35.1	40.9
Aggregates >1 mm, %	June '51	19.0	19.7	19.7	24.6	31.4	21.2	21.7	7.8	8.3
Cation exchange capacity, me/100g	June '51	11.2	11.1	11.1	11.2	11.7	11.8	12.0	8.9	9.4
Total nitrogen, %	June '52	0.132	......	0.137	0.141	0.153	0.142	0.137	0.117	0.124
Organic carbon, %	June '52	1.47	......	1.53	1.64	1.80	1.66	1.67	1.53	1.59
C-N ratio	June '52	11.2	......	11.2	11.7	11.7	11.7	12.2	13.1	12.8

[1]Average of 3 or more replicates in every case.

The data indicate essentially no change in pH in either soil. In the Cheshire loam there was no effect of any of the treatments on either water-holding capacity, moisture equivalent, or total pore space. Bulk density was decreased slightly and cation exchange capacity, capillary porosity, and aggregation >1 mm were increased by the 40-T rate of oak-hickory chips, and capillary porosity and aggregation by both aspen-gray birch and pine chips. Non-capillary porosity was not affected.

The Merrimac soil, on the other hand, was favorably influenced by the 10-T rate of O-H chips in most of the soil properties tested.

Data on samplings made at other times resulted in similar findings.

All treatments increased the total N content of the soil percentagewise. On the basis of analysis, 10 T of chips added about 40 pounds of N. If the final N content of the soil is calculated on a uniform basis, e.g., 1,500, 000 pounds of topsoil per acre (assuming a bulk density of approximately 1.0), the increases in N exceed the amounts added in the chips. However, the application of chips reduced the bulk density, and when the corresponding reduction in weight per acre is taken into account, it turns out that all increases as determined by soil analysis were less than the calculated amounts added in the chips. When dealing with small percentages of N or any other constituent and large weights of soil, the error of estimation can be quite large; hence, it is inadvisable to place too much stress on these findings. It is quite obvious, however, that no great change in N took place.

Plant composition. Spectrographic analyses[1] of the spinach plants in 1949 showed some increase in K content with the increase in chips application. Similar analyses in 1950 gave variable results with no consistent relation to treatment. Analyses of the 1951 beet tops (Table 5)

TABLE 5. MINERAL COMPOSITION[1] OF BEET TOPS GROWN IN CHESHIRE LOAM
Harvested May 11, 1951
(Only the values in **bold** face are significantly higher or lower than the check)

Element		Check	Treatments (10 T/A)		
			O-H chips	ASP-GB chips	Pine chips
		Averages of 3 replicates			
Potassium	%	4.64	3.90	**3.79**	4.24
Calcium	%	2.27	2.43	2.50	2.64
Magnesium	%	1.40	**1.60**	**1.60**	**1.56**
Phosphorus	%	0.33	0.32	0.31	0.33
Iron	%	.028	**.023**	**.021**	.029
Aluminum	%	.022	**.017**	**.016**	.024
Manganese	ppm	173	217	**227**	**310**
Copper	ppm	16	14	15	17
Zinc	ppm	157	160	160	**177**

[1]Determined on the spectrograph by W. T. Mathis, Analytical Chemistry Department.

[1]Mathis, W. T. Anal. Chem. 25:943-947, 1953.

showed a lower concentration of K, Fe and Al from oak-hickory and aspen-gray birch chips but not for pine. To some extent, this reduction is associated with larger plants; hence, in part, it is a dilution effect. On the other hand Mg was definitely higher with all three kinds of chips and Mn was higher with A-GB and pine chips. No explanation is offered for these findings.

Summarizing the results of Expt. Ia and Ib, it is seen that (a) chips did not increase soil acidity; (b) the first crop following treatment required supplementary nitrogen to prevent N deficiency; (c) aspen-gray birch chips decomposed most rapidly and caused the greatest amount of N starvation, and pine was slowest to break down, in some cases requiring little or no extra N; (d) subsequent crops, after the first, generally showed increased yields where chips had been used and particularly where the rate exceeded 10 T/A (although top growth usually increased more than did root growth); and (e) chips treatments generally had a small but favorable effect upon soil properties.

Use of Composted Chips

In a limited pot experiment conducted earlier, it was found that well-rotted sawdust had a very favorable effect on plant growth, in contrast to fresh sawdust. To explore the question further, oak-hickory chips were composted in bins of 1.75 cu yds capacity, and in 12 × 24 inch sewer pipe of about 1.4 cu ft capacity for a 10-month period beginning in December, 1949.

The additive materials included to facilitate composting, and the approximate amounts used for 1.75 cu yds of fresh material were:

Dolomitic limestone	13 pounds
A 11.5-7.7-3.9 fertilizer consisting of 10 parts 5-10-5 and 3 parts ammonium nitrate	24 pounds
Topsoil	¼-½ inch layer

The order of construction, starting at the bottom, was chips, topsoil, limestone, fertilizer, with repeated layers until the bins were full.

Proportionately less material was used in the sewer pipes, which were filled in the same manner as above, with one exception, viz., the entire mass of chips, sludge, soil, lime and fertilizer was well mixed before placing it in the pipe. Watering was left to the elements and the material was not turned or manipulated in any way during the composting period.

At the end of the composting period the various composts, as well as fresh, uncomposted chips and peat moss, were applied to potted Hartford loamy sand in the greenhouse at the rate of 130 cu yds per acre (equivalent to a 1-inch layer). After working them into the soil, it was cropped to beets and spinach. The use of composts on field plots will be mentioned later.

The composition of these various materials (and of rotted sawdust for comparison) are shown in Table 6.

TABLE 6. COMPOSITION OF CHIPS COMPOST AND FRESH MATERIALS

Materials	Total N %	Organic C %	C/N	Loss-on ignition %	Ash %	Cation exch. capacity me/100g
Compost in cinder block bins						
Oak chips alone	0.330	42.1	128.0	98.1	1.9	......
Oak chips + LNPK[1] + soil	0.375	26.4	70.4	51.5	48.5	......
Oak chips + sewage sludge (New Haven)	1.357	35.4	26.1	61.8	38.2	......
Oak chips + sludge + LNPK + soil	0.930	......	......	27.4	72.6	......
Compost in 12 × 24″ clay pipe						
Oak chips alone	0.335	40.3	120.0	94.5	5.5	76.8
Oak chips + LNPK + soil[2]	.525	21.9	41.7	41.7	58.3	46.5
Oak chips + sludge[3]	1.350	37.0	27.4	66.4	33.6	107.4
Oak Chips + sludge + LNPK + soil[4]	.922	17.3	18.8	31.1	68.9	48.6
Oak chips + manure	.508	20.3	40.0	30.9	69.1	......
Birch chips alone	.312	42.7	137.0	98.1	1.9	......
Birch chips + LNPK + soil	.410	19.4	47.3	30.7	69.3	......
Pine chips alone	.312	30.3	97.0	97.5	2.5	......
Pine chips + LNPK + soil	.488	22.2	45.4	41.4	58.6	......
Uncomposted materials						
Chips						
Oak	.212	50.3	238	98.7	1.3	......
Aspen-gray birch	......	49.7	......	98.8	1.2	......
Gray birch	......	51.3	......	99.1	0.9	......
Red pine-white pine	......	53.7	......	99.2	0.8	......
White pine (including needles)	[5]	56.1	[5]	98.8	1.2	......
Peat moss	1.0	51.3	51.3	98.5	1.5	115.0
Rotted sawdust	...	....	......	88.8	11.2	......
Digested sewage sludge (New Haven)	1.50	28.8	19.2	41.7	58.3	25.0

[1]Dolomitic limestone plus 11-8-4 fertilizer.
[2]Estimated C/N of mixture at start – 69.6.
[3]Estimated C/N of mixture at start – 60.0.
[4]Estimated C/N of mixture at start – 43.4.
[5]Salomon gives 0.181% N, 51.8% C, 286 C/N for white pine (Soil Science Society of America Proc. 17:114-118. 1953).

Results

Yields. Yields of the successive crops grown in the greenhouse are given in Table 7. The first crop, beets, was removed early before "beets" had developed. In spite of some wide variations between replicates, the increases or decreases relative to the checks were highly significant. Of chief interest are the following points (see Table 7 for key to symbols

TABLE 7. YIELDS OF SUCCESSIVE CROPS ON HARTFORD LOAMY SAND IN GREENHOUSE POTS TREATED WITH CHIPS COMPOST AND FRESH CHIPS
Fresh weights, in grams per pot

Treatments	Symbol	First crop beets[1] Nov. '50-Jan. '51 Entire plant		Second crop, beets Feb.-May, 1951 Entire plant		Second crop, beets Feb.-May, 1951 "Beets" only		Third crop, spinach Nov.-Dec., 1951		Fourth crop, beets Jan.-May, 1952 Entire plant		Fourth crop, beets Jan.-May, 1952 "Beets" only	
		g	Rel.	g	Rel.	g	Rel.	g	Rel.	g	Rel.	g	Rel.
Check (no chips)	A	33.6	100	107.0	100	48.0	100	15.2	100	164	100	38.7	100
Compost													
Oak chips													
Chips only	B	4.7	14	19.2	18	2.5	5	14.7	97	198	121	72.5*	187
+ LNPK[2]	C	33.8	101	47.8	45	14.5	30	18.1*	118	207	126	37.0	96
+ Sludge[3]	D	52.5	156	116.3	108	42.8	89	10.5	67	222	135	49.5*	128
+ Sludge + LNPK	E	55.7	166	128.8	121	56.0	117	10.7	70	186*	113	31.3	81
+ Manure	I	62.1	185	71.0	66	30.0	63	11.4	75	262	160	93.3	242
Birch chips													
Chips only	M	9.3	27	38.3	36	9.3	19	19.1*	126	241	147	65.7*	170
+ LNPK	N	70.9	211	76.7	71	28.7	61	15.0	99	180	110	24.3	63
Pine chips													
Chips only	O	58.0	173	49.7	47	18.3	37	21.3*	140	200	122	55.0*	142
+ LNPK	P	61.3	183	82.3	77	27.0	56	16.4*	108	171	104	24.0	62
Fresh chips													
Oak	U	1.8	5	4.7	4	0.1	2	21.4*	142	224	137	69.3	179
Oak + N	V	43.8	130	45.7	43	12.3	27	15.3	101	181	110	37.7	98
Oak (×2)[4] + N	W	39.6	118	50.3	47	22.0	46	28.1	185	252	154	86.3	224
Check + N	X	48.5	145	229.0	214	62.3	128	9.2	61	239	146	70.0	181
Peat moss	R	58.3	174	115.0	107	59.0	123	16.3	107	191	116	52.7	136
Peat moss + N	S	52.4	156	220.0	205	69.0	144	15.5	102	230	140	66.7	172
Peat moss (×2) + N	T	48.0	143	272.0	254	81.7	169	21.5	142	204	124	66.7	172

[1]The plants were harvested before the "beets" had developed.
[2]Limestone, 11-8-4 fertilizer, and a little topsoil for inoculation.
[3]Digested sewage sludge from New Haven.
[4]Approximately 260 cu yds per acre. All others, 130 cu yds.
*Differences not significant. All others were significant.

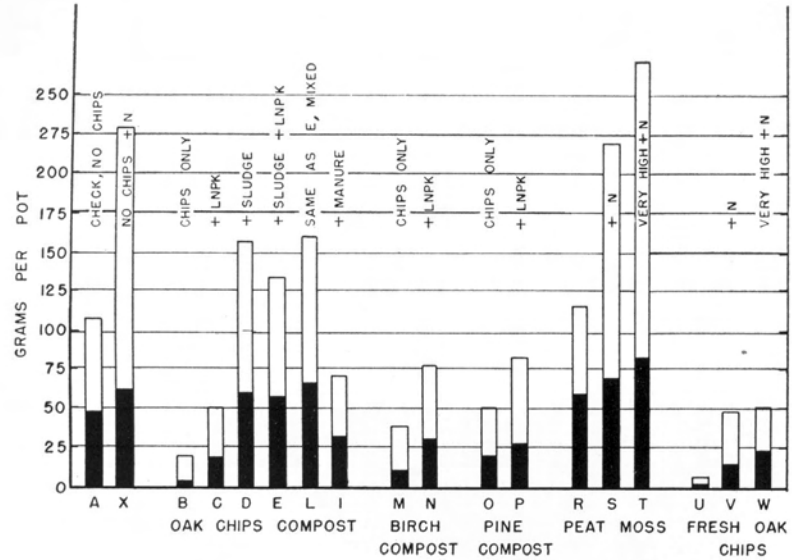

Figure 6. Effect of several composts, peat moss, and fresh oak chips on beet yields in greenhouse pots, 1951. Normal rate of application = 130 cu yds/A; very high = 260 cu yds. (See Table 7 for further details.) Expt. II.

used): (a) pure oak and birch chips composted without supplementary materials were but little more effective than fresh chips so far as plant growth is concerned (B and M vs. U). This result was to be expected considering the slight degree of breakdown. (b) Sludge was beneficial and manure even more so (D, E, and I vs. A and B). (c) Pine chips compost, with or without supplements, was effective (O and P). Note that the C/N of pine compost (97.0), was lower than that of oak – (120), and birch – (137), Table 6. (d) Fresh chips with extra N produced somewhat better yields than the controls (V and W vs. A). (e) Best over-all growth was produced by birch-chips + LNPK (N).

In the second crop, Table 7 and Figure 6, the check + N treatment produced the highest yields, followed in turn by the sludge-treated composts and manure-treated composts, i.e. X > E and D > I.

The third crop, spinach, gave variable results, but there was a considerable leveling of yields. Pure chips compost (B, M and O) compared favorably with other treatments, but the check + N plots (X) showed a marked drop in yield. Growth was less where sludge was a constituent of the compost, thus substantiating the findings in other experiments that spinach plants were adversely affected, as a rule, by sludge treatment. The high yields produced by 260 cu yds of fresh chips + N (W) were significant.

For the fourth and final crop, it is seen that: (a) all three species of pure chips compost were beneficial (B, M and O); (b) with fertilizer and/or sludge, or manure supplements, oak chips compost (C, D, E, I) was beneficial but not birch and pine (N and P); (c) manure (I), once again, showed up as the best supplement, and the very high rate of fresh chips + N (W) ranked second in yields; (d) whenever N was added to the chips, either as fertilizer or as sludge, the increase in top growth was greater than that of the roots.

Looking at Table 7 as a whole, it is seen that pure chips compost and fresh chips greatly restricted plant growth initially but eventually resulted in larger yields than where fertilizers, sludge, or manure were used with the chips. It is theorized that the slower rate of decomposition of pure chips and the consequent delay in liberation of available N worked to the advantage of the fourth crop on these soils, i.e., two years after the original treatment.

These results have been confirmed by Davey (7) who found that composted sawdust applied at the rate of 40 T/A to a sandy soil in greenhouse pots, resulted in marked increases in growth of tree seedlings and red clover as compared with fresh sawdust used at the same rate.

Peat moss (Table 7 and Figure 6), used for comparison with compost and fresh chips, produced good yields when applied either alone or with extra N. This type of organic matter is so resistant to decay that it seldom causes N deficiency.

Soil Properties. The soils were limed initially to pH 6.7-7.2, and all remained above 6.5 through June, 1951 except those treated with peat moss (260 cu yds + N) which dropped to 5.7. The latter received a second liming in the fall of 1951. In the January, 1952 sampling, the pH of all the treatments had dropped somewhat, but lime was added only to the check + N treatment (X). In June, 1952, none were below 6.1.

The use of sludge in the compost, with or without LNPK, resulted in higher nitrates, and sludge caused a higher concentration of available Ca (New Haven sludge is lime-treated). Because all of the soils tested low to very low in potash in June, 1951, the fall treatment that year consisted of 5-5-15 fertilizer – 10 g per pot or 2500 lbs per acre. Subsequent quick tests showed high nitrates and adequate P and K.

The data on cation exchange capacity (CEC) and moisture equivalent are given in Table 8. (See table for symbols which follow.) All organic matter treatments significantly increased CEC, the increases varying from 6 to 42 per cent more than the checks. In general, the highest values were produced by peat moss at the double rate of fresh chips (T). Chips-sludge compost (D and E) proved to be more beneficial than chips-manure compost (I).

As for moisture equivalent, all organic matter treatments except pine chips compost (O) resulted in significant increases, averaging about 13½ per cent for the various chips composts. The 24 per cent increase shown for the oak chips + LNPK (C) appears to be out of line since neither birch (N) nor pine chips (P) compost approach this value.

Highest moisture equivalent values were obtained from the double fresh oak chips treatment (W).

In summary, where chips *compost* were applied to a loamy sand soil, they produced higher yields of the first crop or two than did the checks,

TABLE 8. EFFECT OF COMPOST TREATMENTS ON CATION EXCHANGE CAPACITY AND MOISTURE EQUIVALENT (EXPT. II)
Hartford Loamy Sand

Treatments	Symbol	Cation exchange capacity		Moisture equivalent	
		me/100 g	Rel.	%	Rel.
Check (no chips)	A	4.45	100	6.28	100
Check + N	X	4.44	100	6.41	102
Composts					
Oak chips					
Chips only	B	4.75	106	6.86	109
+ LNPK	C	4.76	106	7.80	124
+ Sludge	D	5.22	117	7.10	113
+ Sludge + LNPK	E	5.17	116	7.08	113
+ Manure	I	4.97	112	7.22	115
Birch chips					
Chips only	M	4.83	109	7.25	115
+ LNPK	N	4.88	110	7.06	112
Pine chips					
Chips only	O	4.73	106	6.56	104
+ LNPK	P	5.53	124	6.44	103
Fresh chips					
Oak	U	4.73	106	7.52	120
Oak + N	V	4.72	106	7.40	118
Oak (× 2)[1] + N	W	5.36	121	8.28	132
Peat moss	R	5.44	122	7.35	117
Peat moss + N	S	5.49	123	6.91	110
Peat moss (× 2)[1] + N	T	6.31	142	7.94	126

[1]Approximately 260 cu yds per acre. All others, 130 cu yds.

and much higher than did fresh chips; but for the third and later crops, fresh chips were about as good and, in some cases, better than the composted materials. It was found that chips composts are effective in improving the soil, particularly where sludge is included. But in some cases (moisture equivalent, for example), fresh chips were more effective than chips compost, comparing well with peat moss.

OUTDOOR SOIL FRAME EXPERIMENTS

Late in 1949, experiments with chips were started in 48 concrete-walled soil frames measuring 25 by 25 inches (0.0001 A), and resting on the parent material (C horizon) of Cheshire loam. Both topsoil (plow layer) and subsoil from a Cheshire loam a few miles away had been trucked in and uniformly placed in the frames in 1944. Crops grown in the interim included millet, beets, rye, vetch and rye, and oats during which time all of the frames were treated identically. Usually 1500 to 2000 pounds of 5-10-10 per acre were applied annually.

In December, 1949, fresh oak, gray birch, and white pine chips were applied at the rates of 10 and 20 tons of dry organic matter per acre and worked into the topsoil (Table 9). There were four series, with treatments randomized within each series. Fertilization consisted of a 4-9-13 mixture applied in the spring of '50, '51, and '52 at 1700 pounds per acre. The 1953 treatment consisted of two top-dressings of 5-10-10 made after the plants had become established. In the original treatments, half of the frames (i.e., Series II and IV) were given ammonium nitrate equivalent to one pound of N per 100 pounds of dry matter, applied in three equal doses—April, May and June, 1950; the other half (Series I and III) received none. Side dressings of nitrogen fertilizer were made to all frames as deemed necessary during 1952 and 1953.

TABLE 9. ORIGINAL AND REVISED TREATMENTS IN THE SOIL FRAMES

Original treatments, all series 1949-53	Revised treatments[1] 1954 (rates per acre) Series I + III	Series II + IV
Check	Check	Check
Check + N	Check + N[2]	Check + N[2]
Oak chips 10 T	Oak chips 50 cu yds + 0.75% N	Oak chips 50 cu yds + 1.5% N
Oak chips 20 T	Oak chips 50 cu yds + 1.5% N	Oak chips 50 cu yds + 0.75% N
Birch chips 10 T	Manure 50 cu yds	Oak chips mulch 50 cu yds
Birch chips 20 T	Oak chips mulch 50 cu yds	Manure 50 cu yds
Pine chips 10 T	Manure 50 cu yds + chips 20 cu yds	Pine chips 50 cu yds + 0.75% N
Pine chips 20 T	Pine chips 50 cu yds + 0.75% N	Manure 50 cu yds + chips 20 cu yds

[1]Equivalent dry weights of 50 cu yds of organic matter: oak chips, 11.24 T; pine chips, 6.06 T; manure, 11.72 T.

[2]Same amount of N as the 0.75% rate used with chips, i.e., 0.75 lb N per 100 lbs dry chips.

Following the 1951 crop, additional lime was applied to equalize the pH in the different frames and to raise it to at least 6.0. Further additions of lime were made later wherever the pH dropped below 5.6.

The crops grown in 1950 were table beets (Perfected Detroit), followed by oats over winter. Beets were again grown in 1951 and 1952 without winter cover crops. In 1953 we changed to snapdragons[1], setting out

[1]Obtained through the courtesy of Walter Ginter, florist, New Haven.

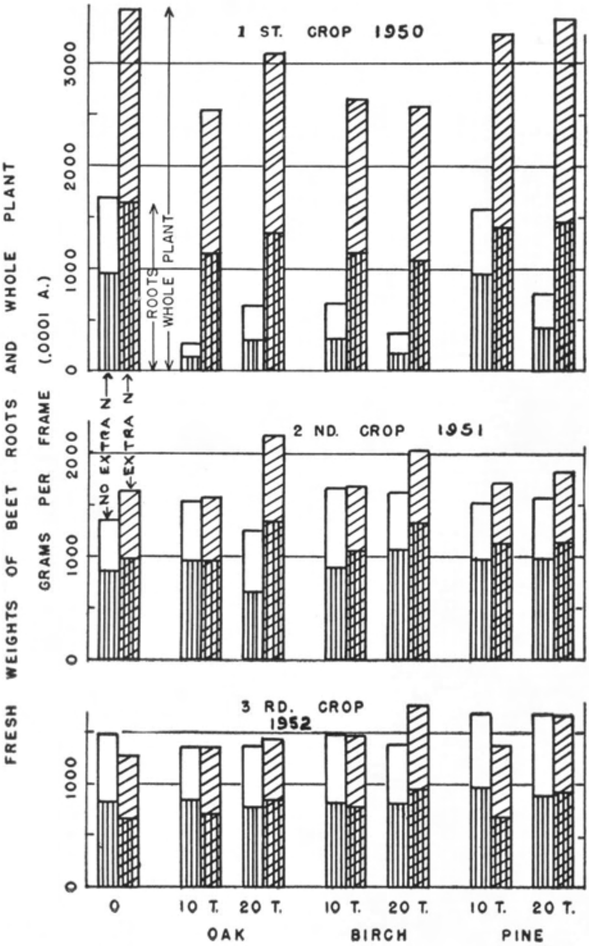

Figure 7. Effect of chips on yields of beets in soil frames containing Cheshire loam. Left bar: no extra nitrogen; right bar with angle hatching: ½% extra nitrogen (applied only once). Lower portion of each bar (verticle hatching) = beet roots; upper portion = beet tops. Expt. III.

Significance of differences: 1st crop, S to HS; 2d crop, only the 10-T/A birch chips increases were significant; 3d crop, not significant.

transplants of two varieties – War Admiral (yellow blooms) on Series I and II, and Twenty Grand (white) on Series III and IV. There were 9 plants per frame.

Early in 1954 treatments were revised to permit comparison of chips + extra N, with manure, with manure + chips, and with a chips mulch. Table 9 lists the old and new treatments, the rates being given in tons or cu yds per acre.

The 1954 crop was table beets. In all of the beet crops, the beets were thinned to about 30 plants per frame; in harvesting, the larger beets were pulled first, leaving the others to grow several weeks or longer.

Results

Plant Growth. Beet yields for the three years 1950-52 are shown in Figure 7. The marked reduction in yields the first year from oak and birch chips gave way in 1951 to moderate increases for all treatments except oak at 20 T/A. Only the birch chips provided significant increases, however. Somewhat higher yields in 1951 were obtained on those frames which had received the original application of extra nitrogen. These increases were greater with 20 T of chips than with the 10-T rate.

In 1952, none of the increases were significant, although the 20-T rate of birch and pine chips with extra N showed appreciable gains.

Table 10 gives a portion of the 1953 data consisting of the total green weight of harvested snapdragon flowers plus the green weight of the plants remaining at the conclusion of bloom harvest. It is obvious that none of the chips treatments were beneficial and in most cases the 20-T rate of birch and pine chips were poorer than the 10-T rate. Series II, which received less shading from an adjoining building than the others, was poorest of the four, and Series III was the best for some unknown reason. The two series, II and IV, which had received the original extra N back in 1950, were generally poorer insofar as weights of flowers and plants were concerned than Series I and III.

Table 10. Effect of Chips on Total Green Weight of Snapdragon Flowers and Plants in Soil Frames, 1953

Average per plant, in grams

Variety	Series	Check	Oak Chips		Birch Chips		Pine Chips	
			10-T/A	20-T/A	10-T/A	20-T/A	10-T/A	20-T/A
War Admiral	I	71.7	64.1	90.9	67.6	56.7	87.1	43.6
(yellow)	III	92.5	73.3	87.4	103.1	94.9	63.2	69.1
Twenty Grand	II	54.1	43.3	42.8	65.8	49.9	55.7	43.3
(white)	IV	88.5	83.7	67.0	62.5	63.9	76.8	60.0
	Av.	76.7	66.1	72.0	74.7	66.4	70.7	54.0

Other data, such as height of stems and number of blooms per plant show essentially the same results and are not given here.

It is difficult to explain the negative results with snapdragons, particularly in the light of earlier benefits for beets. A mere lack of response, that is, if treated and untreated plants were about alike, would indicate either "exhaustion" of the benefits of the treatment, or that snapdragons are less responsive than beets. But the fact that most of the yields tended to be poorer under treatment than in the controls is more puzzling.

Yields of beets in 1954 are given in Table 11. The effects of the treatments, all of which were significant to highly significant, were as follows:

(1) Growth was increased about 50 per cent by the low rate of extra N as compared with the checks. Where oak chips were included, the increase was only about 32 per cent, and with pine chips only 15 per cent.

(2) Doubling the N produced the highest yields in spite of the presence of oak chips; and the manure treatment was essentially as good.

(3) Including chips with manure appreciably reduced yields in three cases out of four.

(4) The chips mulch had practically no beneficial effect on plant growth.

TABLE 11. YIELD OF BEETS IN SOIL FRAMES, 1954
Average weight of beets only, g per plant

Series (replicates)	Check	Check + N[1]	Oak-hickory chips: 50 cu yds + N 0.75%	Oak-hickory chips: 50 cu yds + N 1.5%	Oak-hickory chips: Mulch 50 cu yds	Manure 50 cu yds	Manure 50 + chips 20 cu yds	Pine chips + N 0.75% 50 cu yds
I	14.9	24.0	29.4	34.0	20.8	32.2	20.7	16.6
III	22.0	29.1	35.0	28.3	15.0	36.4	31.0	31.4
II	22.7	40.1	29.9	45.4	25.6	47.3	50.2	21.1
IV	22.4	34.4	14.0	50.1	19.3	36.1	27.1	24.9
Av.	20.5	31.9	27.1	39.5	20.2	38.0	32.2	23.5
Rel.	100	156	132	192	98.5	185	157	115

[1]Same amount of N as used with chips where the rate was 0.75 lbs of N per 100 lbs of dry chips.

The tendency in this particular test for the pine chips to reduce yields more than did oak chips is contrary to our previous experience. It is particularly strange in light of the fact that in this test the amount of pine chips was less in weight than (although equal in volume to) the oak chips. In all of the earlier experiments, equal weights of pine and oak chips were used.

Soil Properties. The principal data on soil properties are given in Table 12. In the sampling of August, 1950, the only significant benefits from treatment were a 4 per cent increase in moisture equivalent and a 7 per cent increase in loss-on-ignition with 20 T/A of pine chips.

A year later, September, 1951, it was found that all of the chips treatments resulted in significant increases of 7 to 13 per cent in loss-on-ignition, the greatest increases coming from 20 T/A of pine. Limited data on organic carbon showed confirming results, the increases ranging up to 24 per cent.

Cation exchange capacity increases did not exceed 5 per cent and the differences lacked significance. Bulk density was reduced slightly, 3-7 per cent, chiefly by the 20-T rates. Non-capillary porosity was increased 9 to 14 per cent by the 20-T rates.

TABLE 12. EFFECT OF CHIPS ON SOIL PROPERTIES OF CHESHIRE LOAM IN CONCRETE FRAMES

Treatments	1950 Sampling		1951 Sampling		1952 Sampling						
	Loss on ignition %	Mois-ture equiv. %	Loss on ignition %	Cation exch. capacity me/100 g	Total N %	Organic C %	C/N	Cation exch. capacity me/100 g	Aggre-gates >1 mm %	Non-capil-lary pore space %	Field moisture capacity %
Check	5.82	17.7	5.28	10.74	0.126	1.41	11.2	11.57	5.26	25.3	24.3
Oak chips 10 T/A	5.82	17.9	5.72	11.01	.128	1.54	12.0	11.55	6.77	27.1	24.6
20 T/A	5.87	17.5	5.68	11.18	.132	1.61	12.2	11.59	7.48	24.9	24.8
Birch chips 10 T/A	5.55	17.9	5.64	11.08	.127	1.57	12.3	11.70	6.90	27.0	25.3
20 T/A	5.90	18.1	5.81	11.29	.133	1.71	12.9	11.77	10.11	28.8	24.5
Pine chips 10 T/A	5.74	17.8	5.71	10.96	.132	1.57	11.9	11.65	7.64	26.9	25.2
20 T/A	6.25	18.2	5.96	11.25	.133	1.85	13.9	12.65	8.06	28.0	25.7

Soil data for samples taken in March, 1952 show, first, a slight increase in total N from the 20-T rates of oak and birch chips and from both rates of pine chips but only the latter were significant. These increases were not in excess of the amount of N added in the chips. The data are averages from the frames with and without the original extra N treatment. Second, there were appreciable increases in organic carbon (and organic matter) ranging from 9 to 32 per cent, but only the 20-T rates were significant. Thirdly, the C-N ratios were essentially uniform except pine at 20-T, which was higher. Fourth, there was essentially no change in CEC except for the 20-T pine rate which caused a 9 per cent increase; and finally, birch and pine chips caused significant increases in aggregates >1 mm, ranging from 20 to 92 per cent.

A second sampling in 1952, November, nearly three years after the first application of chips, produced the following results: (a) bulk density – small but significant decreases (3.5 to 4.8%) for all chips treatments; (b) total pore space – 3 to 4 per cent increases for all treatments; (c) non-capillary pore space – 14 per cent increase for 20-T birch, and 11 per cent increase for 20-T pine. Treatments had no effect on capillary pore space, and only the pine chips increased field moisture capacity. The latter values were determined again a week later, with identical results.

Field moisture capacity in the November, 1954 sampling is shown in Table 13. All of the organic matter treatments resulted in significant increases ranging from 7 to 15 per cent but with little difference between chips alone and manure alone. The oak-hickory chips mulch was about as effective as were the chips incorporated into the soil.

TABLE 13. EFFECT OF CHIPS AND MANURE ON FIELD CAPACITY, LOSS-ON-IGNITION AND CATION EXCHANGE CAPACITY[1]

	Treatments	Field moisture capacity %	Loss-on-ignition %	Cation exchange capacity me/100 g
A	Check	23.0	5.15	8.93
B	Check + N[2]	22.0	5.30	9.47
	Oak-hickory chips			
C	50 cu yds + N 0.75%	25.1	5.75	10.10
D	50 cu yds + N 1.5%	24.8	5.67	9.30
F	50 cu yds mulch	25.8	5.50	9.45
E	Manure 50 cu yds	24.4	6.05	9.87
G	Manure 50 + O-H chips 20 cu yds	26.3	6.00	9.77
H	Pine chips 50 cu yds + N 0.75%	24.3	5.53	9.23
	Significance of differences[3]	HS	HS	ns

[1]Averages of 4 replicates in all cases.
[2]Used same amount of N as treatments C and H.
[3]HS = highly significant; ns = not significant.

Summarizing the soil frame experiments, it was found that fresh chips, with supplementary N, markedly reduced yields of the first crop although the 10-T rate of pine was nearly as good as the check. Second year crop yields were increased slightly by all except 20-T oak chips, but there was no benefit for the third crop of beets. Where extra N was applied initially, yields the first year were almost as good as the check + N, and in the second and third years the 20-T rate of chips resulted in appreciable increases.

The fourth season crop, snapdragons, turned out to be somewhat poorer wherever chips had been used, either with or without the original extra N.

The 1954 beet crop following revision of the treatments showed that yields with chips could be satisfactory if sufficient N is applied and, in fact, could be approximately as good as those produced by an equal volume of manure. A chips mulch was not effective.

As for the soil it was found that, in general, chips treatments had a favorable effect, chiefly in the amount of aggregates >1 mm, and in organic matter content. Water-holding capacity, as represented by the moisture equivalent determination, and the cation exchange capacity were increased slightly (3 to 5 per cent), and bulk density was decreased 3 to 7 per cent. Non-capillary porosity was usually increased by the 20-T rate. In the final (1954) sampling field moisture capacity was increased 7 to 15 per cent by all chips and manure treatments including chips mulch.

FIELD EXPERIMENTS

Mt. Carmel Farm

Oak chips were applied in December, 1949 to small 12 by 15 foot plots on Cheshire loam. This piece of land had grown potatoes and corn for a number of years previously. All treatments were in triplicate, randomized, and the rates were 5 and 10 tons of dry matter per acre with no additional nitrogen applied. A green manure crop of rye was on the ground at the time and this was plowed under and field corn (Ohio M-15) planted in the spring of 1950, at 18 × 36 inch spacing. The hills were thinned later to 1 and 2 plants, respectively per hill.

In the fall of 1950, additional plots were laid out and treated with composted chips, fresh oak chips, and a fresh oak chip mulch as indicated in Table 15. In these cases the quantity of organic matter applied was 6 bu per plot of 180 sq ft or about 67 cu yds per acre. The amounts in pounds of dry matter per acre are given in the footnotes of Table 15. All plots received a uniform application of 1600 pounds of 5-10-10 fertilizer each spring before the corn was planted.

Field corn was grown on all plots in 1951 and again in 1953. No results were obtained in 1952, the area being planted to rape which was plowed under in the fall.

Results

Yields. The 1949 treatment of chips resulted in marked nitrogen deficiency in the rye and in the following (1950) corn crop as seen in Table 14. Corn yields for the 5 and 10-T rates averaged only 67 and 51 per cent, respectively, of the control plot yields. In 1951, corn yields were 87 and 86 per cent of the checks and in 1953, 108 and 99 per cent, respectively.

TABLE 14. EFFECT OF WOODCHIPS ON CORN YIELES, MT. CARMEL FARM
Bushels per acre, calculated to 15.5% moisture and 70 lbs/bu

Series (replicates)		Check	Oak chips 5 T/A	Oak chips 10 T/A
		1950 Crop		
I		79	65	75
II		101	45	28
III		104	81	43
	Av.	94.7	63.7	48.7
	Rel.	100	67	51
		1951 Crop		
I		104	82	102
II		103	101	82
III		116	99	95
	Av.	107.7	94	93
	Rel.	100	87	86
		1953 Crop		
I		79	82	83
II		86	89	80
III		77	91	76
	Av.	80.7	87.3	79.7
	Rel.	100	108	99

Composting chips before using them resulted, in 1951, in less decrease in yields, Table 15, but no increases. Fresh chips + N and mulch + N gave better yields which were still 5 to 6 per cent below the checks. However, none of the differences can be considered significant. The 1951 growing season was an unusually favorable one for corn; thus, any benefits resulting from an improvement in the physical properties of the soil would be less likely to show up in the yields.

The 1953 season was a normal one and the plot yield data are dependable. As seen in Table 15 differences were extremely slight and insignificant.

It is quite probable that the results on these field plots would have been different had larger amounts of supplemental N been used and, perhaps, if somewhat lower applications of complete fertilizer had been made as the over-all treatment.

Peoples State Forest Nursery

In August, 1951, 21 plots each 10 × 36 feet were laid out in area No. 4 of Peoples Forest Nursery, Barkhamsted, Connecticut, for an experiment with coniferous forest tree seedbeds. The soil was Merrimac sandy loam, acid in reaction (pH 5.1), and generally low in fertility.

TABLE 15. EFFECT OF CHIPS COMPOST[1] AND FRESH CHIPS ON CORN YIELDS, MT. CARMEL FARM

Bushels per acre, calculated to 15.5% moisture and 70 lbs per bushels

Series (replicates)		Check	Composted oak chips[2]				Fresh oak chips[2]			
			Chips only Bin 1	Chips + LNPK Bin 2	Chips + sludge Bin 3	Chips + sludge + LNPK Bin 4	Chips only	Chips + N[3]	Mulch	Mulch + N[3]
					1951 Crop					
IV		101	81	105	98	92	96	110	97	110
V		116	107	98	99	94	79	109	100	105
VI		113	103	103	96	101	92	90	80	99
	Av.	110	97	102	97.7	95.7	89	103	92.3	104.7
	Rel.	100	88	93	89	87	81	94	84	95
					1953 Crop					
IV		78	88	84	81	87	92	86	......	......
V		98	98	91	93	95	89	96	......	......
VI		91	85	95	89	88	86	89	......	......
	Av.	89	90.3	90	87.7	90	89	90.3	......	......
	Rel.	100	101	101	99	101	100	101	......	......

[1]See page 16.

[2]Approximately 67 cu yds per A or the following dry weights in tons per acre: from Bin 1, 9.8 T; Bin 2, 18.5 T; Bin 3, 10.3 T; Bin 4, 16.1 T; fresh chips, 10.2 T.

[3]Approximately 0.4 pounds of N per 100 pounds of dry chips.

Previously in grass, this lot was plowed and limed in the fall of 1949. The following spring it received 8-16-16 fertilizer at the rate of about 250 lbs per acre and was then seeded to rye which was plowed under when mature. This was followed by rye in the fall of 1950 and two successive crops of buckwheat in the summer of 1951. Between buckwheat crops, the area received a miscellaneous mixture of fertilizers which approximated 500 lbs of 16-8-8 per acre.

Treatments on the plots consisted of sawdust (about equal proportions of hardwood and softwood) and sawdust plus digested sewage sludge (pH 5.6) from the Torrington, Connecticut, treatment plant. The treatments, all in triplicate but not randomized, were as follows:

A_1 Sawdust mulch 1 inch thick } (applied immediately after seeding pine and spruce).
A_2 Sawdust mulch 2 inches thick }

B Sawdust, 50 cu yds per acre (9 bu/plot) harrowed in.

C Sawdust, 150 cu yds per acre (27 bu/plot) harrowed in.

D Check (control)

G { Sawdust 50 cu yds per acre, harrowed in.
Sludge 50 cu yds per acre, harrowed in.

Late in the fall of 1951, seven rows of seedbeds were laid out crossways of the plots and seeded as follows:

Row nos.	*Species*	*Series (replicates)*	*Treatments*
4 and 5	White pine	1, 2, 3	All
6	Jack pine	1	A - D
	White pine	1	G
	White pine	2, 3	All
7	Jack pine	1	A - D
	Red pine	1	G
	Red pine	2, 3	All
8	Red pine	1, 2, 3	All
9	Norway spruce	1, 2, 3	All
10	White spruce	1, 2, 3	All

In November, 1952, the entire area received a top-dressing of castor pomace at the rate of 1200 pounds per acre. Late in April, 1953, the beds received 5/8 pound of 7-7-7 fertilizer per bed or 567 pounds per acre, and a similar treatment May 5 and 13. Dolomitic limestone was applied May 26 at 1500 pounds per acre, and on July 14, 600 pounds of castor pomace and 300 of 7-7-7 per acre.

The fertilizers used in this field and the sludge applied to certain plots increased the acidity of the soil; thus, the original lime applications proved to be too light. All of the plots were usually below pH 5.2. The range at the final sampling in Semptember, 1953, was 4.5 to 5.5.

In the fall of 1952, counts were made of the number of trees in four square feet on each plot. Also, a rough estimate of relative heights of plants was obtained and notes made on general appearances. In the spring of 1953, total heights were obtained of the trees in two 3 × 6 inch or 6 × 6-inch marked areas of each plot. In late summer the same trees were remeasured, thus providing growth data for 1953.

Results

Stand Density. Although the counts were quite variable, the averages shown in Table 16 give a general picture of the situation. The one-inch sawdust mulch reduced the stand of all species except white pine; and the two-inch layer reduced white pine by two-thirds and all other species

TABLE 16. STAND DENSITY OF 1-0[1] FOREST TREE SEEDLINGS AS AFFECTED BY TREATMENT
Average number per square foot

Species	Sawdust mulch		Sawdust		Check	Sawdust + sludge
	1 inch	2 inches	50 cu yds	150 cu yds		50 cu yds each
White pine	33	13	24	21	28	27
Jack pine	42	1	73	74	82	....
Red pine	70	11	121	102	125	99
Norway spruce	23	13	47	29	41	38
White spruce	57	4	129	123	114	92

[1]1-0 = one year in the seedbed and none in the transplant bed.

considerably more. In fact, several plots showed not a single seedling in the 4 × 4-foot treated area. Presumably the seeds germinated but the seedlings were killed by damping-off fungi.

Where the sawdust was incorporated into the soil, the 50-yd rate had practically no effect, but the 150-yd rate appeared to cause some reduction in all species except white spruce. Where sludge was included with sawdust, there was a slight reduction in some cases.

First Year Growth. Observations and spot measurements indicated that sawdust mulch generally favored growth of the seedlings that did come through. While the factor of reduction in competition may have played a role, it is not believed to have been a very important element in these cases, for there were ample instances of low stand density in other treatments which did not reflect increases in growth.

The other treatments were not consistent in their effect, and little of value can be gleaned from the results.

Second Year Growth. The growth data obtained in the fall of 1953 are recorded in Table 17. Comments by species are as follows:

White pine: Growth was increased about 16½ per cent by the mulches, there being little difference between 1 and 2-inch depths. Sawdust incorporated into the soil had no appreciable effect whether with or without sludge.

Jack pine: Full evaluation is not possible with the limited data available. It appears that the 1-inch mulch increased growth somewhat, possibly as much as 25 per cent. Sawdust in the soil had no consistent effect.

Red pine: Seedlings on the mulched plots were 9 and 25 per cent taller, respectively, for the one and two-inch depths, while sawdust *in* the soil generally resulted in slightly smaller plants than the checks. Where sludge and sawdust were applied together there was no significant effect on seedling growth.

Norway spruce: Growth was increased by as much as 22 per cent by mulching. The 50-yd rate of incorporated sawdust favored growth by the same amount but the 150-yd rate had no clear-cut effect, nor did the sludge-plus-sawdust.

White spruce: Although the over-all differences between treatments were not significant, there was an indication that the 1-inch mulch, the

TABLE 17. EFFECT OF TREATMENTS ON THE 1953 GROWTH OF FOREST TREE SEEDLINGS, MERRIMAC SANDY LOAM

Averages of three replicates except where otherwise indicated.
Centimeters per tree

	Row no.	Sawdust mulch 1 inch A_1	Sawdust mulch 2 inches A_2	Sawdust 50 cu yds B	Sawdust 150 cu yds C	Check D	Sawdust + sludge 50 cu yds each G
White pine	4	7.44	6.79	6.11	6.80	5.95	6.61
	5	5.70	6.21	4.55	5.30	5.43	4.88
	6	6.87[1]	6.97[1]	6.03[1]	5.46[1]	5.69[1]	5.43
	Av.	6.65	6.62	5.51	5.93	5.69	5.64
	Rel.	117	116	97	104	100	99
Jack pine[2]	6	26.8	19.9	21.4	24.1	18.6	......
	7	18.8	......	18.0	16.9	17.7	......
	Av.	22.8	19.9	19.7	20.5	18.2	......
	Rel.	125	109	108	110	100	......
Red pine	7	4.22[1]	4.86[1]	3.18[1]	2.81[1]	3.67[1]	3.52
	8	3.99	4.53	3.50	3.68	3.79	3.63
	Av.	4.08	4.66	3.37	3.33	3.74	3.57
	Rel.	109	125	90	89	100	95
Norway spruce	9	13.18	13.86	13.89	9.98	11.38	13.37
	Rel.	116	122	122	88	100	117
White spruce	10	11.8	10.7[1]	12.57	12.49	11.03	13.41
	Rel.	107	99	114	113	100	122

[1]Average of 2 replicates.
[2]No replicates; only one plot in each row.

50 and 150 yds of sawdust and the sawdust-sludge mixture were generally favorable to growth of this species.

Soil Properties. Soil samples collected two years after the treatments were applied were tested for pH and loss-on-ignition. The mean pH at that time was 4.91 with essentially no differences between treatments.

Although the over-all effects of the treatments on loss-on-ignition were small and not significant, one treatment, 150 yds of sawdust, resulted in a significant increase, ranging up to 28 per cent.

Further Experience with Sawdust

Mention should be made of another field in the nursery (area 5) previously in grass and trees, which was cleared and plowed in 1950. The soil was Windsor loamy sand. A cover crop of buckwheat was plowed under in June, 1951, followed by an application of 16-8-8 at 500 lbs per acre. A second crop of buckwheat was plowed under in July; in August the area received a moderate application of sawdust estimated at 50 cu yds per acre. In order to test heavier treatments of sawdust, an additional application at the same rate was applied to four 20-ft wide strips running crossways of the area. Two of these received extra N fertilizer at about one pound of N for each 100 lbs of dry matter added. Seeding of spruces and pines was done in the fall of 1951.

Here, the effects of sawdust on this light, acid soil (pH about 5.0) were generally detrimental the first year. The seedlings were extremely small and yellowish in color and in many beds the stand was poor. Where the additional sawdust was applied, with or without extra N, the stands were extremely poor. In fact, by the end of the summer consideration was given to plowing the trees under and starting all over again.

However, it was decided to salvage the beds if possible, and an application of limestone and ANL (ammonium nitrate and lime) was made at the rates of 550 and 270 pounds per A, respectively. In the spring of 1953, additional fertilizers and lime were applied with the result that the seedlings greened up markedly and put on considerable growth. Undoubtedly, some improvement would have occurred without the spring treatments but it was safer to make them.

In summarizing the work at this nursery, it appears that sawdust *mulch* in the quantities used was generally detrimental to stand density, but decidedly beneficial once the seedlings came through it.

Sawdust incorporated into the soil had no appreciable effect on either white pine or Jack pine; it lessened growth of red pine slightly and tended to favor growth of spruces. The only measured benefit to the soil was an increase in loss-on-ignition by the 150 cu yd rate of sawdust.

On the lighter soil in area 5 which also was too acid, fresh sawdust was detrimental. The unfavorable effect might have been avoided by applying sufficient extra nitrogen to narrow the C-N ratio or by using composted sawdust and by waiting about a year before seeding.

It is recognized that the better way to use wood waste in the forest nursery is to apply it prior to seeding a green manure crop, preferably a legume, and it is expected that this practice will be followed in the future on this nursery. Crossitt (6) reports similar experiences in forest nurseries in the South where the trend is now to use sawdust in the manner indicated.

Commercial Nursery

Twenty-four plots were laid out on Hartford sandy loam in a commercial nursery near Wallingford, Connecticut, in October, 1951. There were six treatments replicated four times but not randomized. The plots in Series I and II were 12 by 27 ft, and in Series III and IV, 10½ by 38 ft. Treatments consisted of 50 and 150 cu yds per acre of white pine woodchips[1] and 50 cu yds of chips plus 50 of digested sewage sludge from the Wallingford treatment plant. The sludge was applied October 29, 1951; the chips on March 25, 1952.

The area had received a light dressing of horse manure prior to the chips treatments. An application of 7-7-7 fertilizer at approximately 500 pounds per acre was made in the spring of 1952 and again in 1953.

Budded one-year apple trees were planted in the spring of 1952. In July it seemed that the chip-treated trees were not doing as well as the others, so to avoid possible losses to the nurseryman, the 50 and 150 cu yd treatments were given ammonium nitrate at the rate of one pound of N for each 100 lbs of dry chips applied.

The trees were cut back to within 2 or 3 inches of the ground level in the spring of 1953. Early in September measurements were taken of total heights of the new growth and stem diameter at a point 12 inches above the cutback point.

In March, 1954, they were again cut back, this time to 3½ feet, and the 1954 growth was measured in September.

Results

The trees on the plots included a number of varieties, some of which were on different root stocks. Unfortunately, no one variety occurred on all four series. Measurements were confined to two varieties on two different root stocks on Series I and II; and seven varieties, all on the same root stock on Series III and IV. The data are shown in Tables 18 and 19. Figure 8 shows graphically the percentage increase or decrease in relation to growth on the check plots.

In 1953, growth of **Baldwin**, **Cortland,** and **Macoun** varieties, all on standard root stock, was increased by chips, the gains being 15 to 25 per cent, with little to choose between treatments. **McIntosh on stock IX** showed about 30 per cent increase for the 50 yd rate and half as much for the chips-sludge treatment; while three varieties, **McIntosh on**

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[1]Obtained from Tranquillity Farm, Middlebury, Connecticut, through the courtesy of Charles Miller.

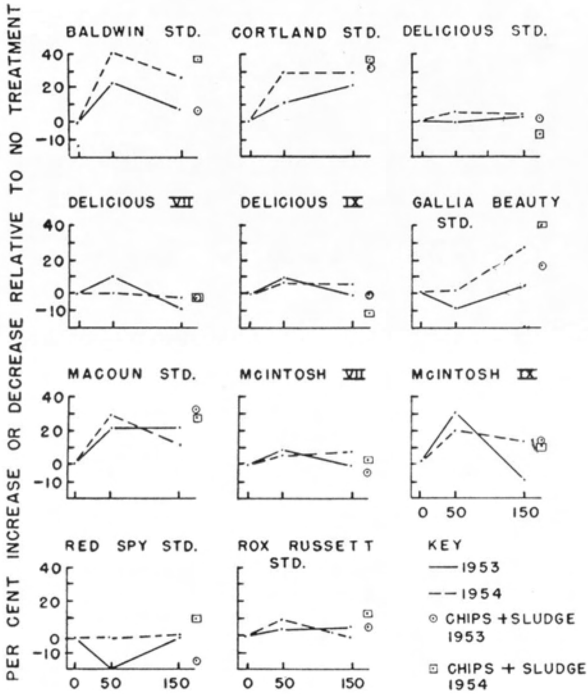

Figure 8. Effect of woodchips alone and in conjunction with digested sewage sludge on growth of apple trees. Shown as per cent increase or decrease in relation to growth of the no-treatment check plots. The rates are 50 and 150 cu yds of chips per acre, and 50 cu yds each of chips and sludge.

stock VII, Delicious on stock VII and **Delicious on stock IX,** responded with a modest 8 per cent for the 50-yd rate only.

Three varieties, **Delicious, Gallia Beauty,** and **Rox Russet,** all on standard stock, were essentially uninfluenced by chips or chips-sludge treatments. The few increases shown were not significant. Finally, one variety, **Red Spy**, was adversely affected by 50 yds of chips and by the chips-sludge treatments.

Although lack of sufficient replication of any one variety prevented use of statistical analyses in the usual manner, if we consider the first four varieties in Table 18 as four replicates of one variety, we obtain significance at the 5 per cent point for treatments and high significance for 'replicates'.

In 1954, **Baldwin, Cortland,** and **Macoun** were again at the top of the list so far as response to treatment goes, and close behind were **Gallia Beauty** and **McIntosh**, the latter on **Malling IX stock.** In all of the other varieties, treatment effects varied from slightly beneficial to slightly detrimental.

TABLE 18. EFFECT OF TREATMENTS ON GROWTH OF YOUNG APPLE TREES ON HARTFORD SANDY LOAM, 1953

Averages of two series in each case

Variety No	Variety	Stock	Heights, in feet				Stem diameters, in inches, at 1 foot above ground			
			Check	Chips 50	Chips 150	Chips 50 Sludge 50	Check	Chips 50	Chips 150	Chips 50 Sludge 50
		Treatment beneficial at 50, 150 and 50-50 cu yds								
6	Baldwin	Standard	3.65	4.53	3.94	3.91	0.351	0.421	0.400	0.385
7	Cortland	"	2.89	3.24*	3.51	3.85	.287	.342	.337	.387
8	Macoun	"	2.66	3.25	3.23	3.50	.300	.341	.347	.397
		Av.	3.07	3.67	3.56	3.75	.313	.368	.361	.390
		Rel.	100	120	116	122	100	118	115	125
		Treatment beneficial at 50, and 50-50 cu yds								
3	McIntosh	Malling IX	2.59	3.40	2.39*	2.98	.242	.312	.252*	.282
		Rel.	100	131	92	115	100	129	104	117
		Treatment beneficial at 50 cu yds only								
1	McIntosh	Malling VII	3.48	3.72	3.45	3.35	.296	.303	.289	.296
2	Delicious	" VII	3.33	3.63	3.05	3.32	.302	.325	.268*	.303
4	Delicious	" IX	2.86	3.12	2.83	2.85	.292	.300	.265*	.256
		Av.	3.22	3.49	3.11	3.17	.297	.309	.274	.285
		Rel.	100	108	96	98	100	104	92	96
		All treatments ineffectual								
5	Delicous	Standard	3.33	3.32	3.45	3.44	.304	.335*	.361	.337
9	Gallia Beauty	"	3.20	2.95*	3.37	3.73*	.335	.329	.366*	.422*
11	Rox Russet	"	3.63	3.78	3.72	3.86*	.350	.394	.370*	.395*
		Av.	3.39	3.35	3.51	3.68	.330	.353	.366	.385
		Rel.	100	99	104	108	100	107	111	117
		Treatment detrimental at 50 and 50-50 cu yds								
10	Red Spy	Standard	3.46	2.76	3.40	3.02	.335	.268	.333	.328
		Rel.	100	80	98	87	100	80	99	98

*Replicates variable, not significant.

TABLE 19. EFFECT OF TREATMENT ON GROWTH OF YOUNG APPLE TREES, HARTFORD SANDY LOAM, 1954

Averages of two series (replicates) in each case

			Growth, in feet[1]			
				Pine chips		
Variety no.	Variety	Root stock	Check	50 yds/A	150 yds/A	Chips 50 yds + sludge 50 yds/A.
		Varieties showing moderate increases				
6	Baldwin	Standard	2.29	3.24	2.89	3.17
7	Cortland	"	2.17	2.80	2.77	2.95
8	Macoun	"	2.13	2.73	2.49	2.74
9	Gallia Beauty	"	2.03	2.06	2.59	2.86
3	McIntosh	Malling IX	2.09	2.51	2.33	2.35
		Av.	2.14	2.67	2.61	2.81
		Rel.	100	124	122	131
		Varieties showing small increases				
11	Rox Russett	Standard	2.49	2.71	2.50	2.83
10	Red Spy	"	2.47	2.45	2.51	2.75
		Av.	2.48	2.58	2.50	2.78
		Rel.	100	104	102	112
		Varieties showing slight increases to slight adverse effects				
1	McIntosh	Malling VII	2.59	2.75	2.77	2.66
4	Delicious	" IX	2.03	2.17	2.12	1.79
5	"	Standard	2.73	2.87	2.87	2.57
2	"	Malling VII	2.67	2.69	2.59	2.64
		Av.	2.50	2.62	2.59	2.41
		Rel.	100	104	103	96

[1]The trees had been headed back to 3½ feet in March. Only the 1954 growth was measured.

Discussion

TOXIC EFFECTS

In none of the experiments has there been any evidence of toxicity to plants as a result of applying chips or sawdust from any of the species used – aspen, birch, hickory, oak, red pine, and white pine. Any and all injurious effects have been attributed to nitrogen starvation. It is recognized that there may be species which do have toxic effects. Walnut and cedar have been mentioned. Waring (22) using gum, mahogany, iron bark, and messmate was of the opinion that the sawdust of these species may have a poisonous effect on plant roots.

Also, there may be a difference in crops in this respect. Bear and Prince (4) found that 2½ tons of pine shavings per acre interfered with germination and growth of carrots, especially in wet seasons, but had no such effect on snap beans. The same amount of oak shavings gave no difficulty. The present work showed a beneficial effect of all chips, including pine, on germination of lettuce. This is attributed to the accompanying reduction in available nitrogen brought about by the chips. Inasmuch as pine chips decomposed more slowly and thus had a lesser effect on nitrate content, the increase in germination from pine chips was less than the increase from oak and birch chips. No case was found of a reduction in germination from chips.

PLANT GROWTH

The several experiments herein reported show that yields of the first crop following treatment with woodchips are largely controlled by the supply of available N, assuming an adequate supply of other nutrients. If sufficient nitrogen is provided, the yields will be as large as they would be from any combination of organic materials and nitrogen. The inclusion of chips or sawdust with fertilizer, commercial or manure or both, will usually reduce the yield over the same amount of fertilizer without chips. Salomon's data (18) show the same situation, although his procedure of maintaining a given level of nitrates by periodic application of sodium nitrate lessened the reduction and in some cases eliminated it.

Yields of subsequent crops on the same soil with no further chips application is a different story. The nitrogen tied up during the initial period of cellulose decomposition is released with benefit to the crop. Thus, with a given fertilizer application, yields are likely to be higher where chips or sawdust have been used than they would be with the fertilizer alone.

This last statement has been more true in the greenhouse and soil frames than it was in the field. Field corn, pine seedlings, and some varieties of apple trees made no response to chips or sawdust treatment; but the spruces and other apple varieties did respond favorably.

Salomon's (18) findings that oak chips decomposed more rapidly than pine is in agreement with these results. Upon sieving the soil at the end of 12 and 24 months following treatment, he found fewer oak than pine chips remaining.

With reference to corn, Dunn *et al.* (9) applied fresh and rotted sawdust and manure to field plots on Merrimac loamy coarse sand. They obtained no *significant* differences in corn yields over a four-year period, although the rotted sawdust plots consistently outyielded all other treatments. These investigators avoided depressed yields from fresh sawdust by making heavy applications of N fertilizer each of the first three years.

SOIL PROPERTIES

Soil reaction

All of the experiments in this study confirm fully the reports of other investigators (2, 18) that the more common wood wastes do not increase soil acidity. The initial effect is to decrease it slightly.

Nitrogen and carbon

In most cases chips resulted in some increase in nitrogen which generally did not exceed the amount added in the chips. This is in agreement with Salomon's findings (18) that changes in N were negligible. There was no evidence that the application of organic matter to the soil favors non-symbiotic nitrogen fixation as claimed by Dhar (8).

Significant carbon increases in the soil were obtained only by the 20-T/A pine chips treatment, the increase being about 35 per cent of the amount of C added in the chips.

Other soil properties

The chief benefit to the soil as determined in these studies was the increase in aggregation into particles >1 mm ranging from 12 to 90 per cent, and a 3 to 7 per cent decrease in bulk density. Increases in cation exchange capacity, pore space, non-capillary pore space, field moisture capacity, and moisture equivalent were usually small, varying from 0 to 10 per cent.

WOOD WASTE MULCH

In this work, the use of chips or sawdust as a mulch was only a minor aspect of the study. It was felt that the general benefits of mulching are pretty well known and accepted, although of course measured results are always helpful in establishing a fact.

The limited one season test of mulching corn did not prove beneficial. Likewise, in the soil frames in 1954, a chips mulch did not benefit the beet crop. Mulching forest nursery seedbeds, although detrimental because the sawdust application was too heavy, indicated a definite beneficial effect on seedling growth of those plants which managed to get through the mulch. With a much lighter application the bad effect on the stand would undoubtedly have been eliminated. A one-fourth inch layer of sawdust has given excellent results in loblolly and slash pine seed beds in the South (16).

That a sawdust mulch contributes some substance favorable to plant growth aside from the physical benefits to the soil has been indicated by the Rhode Island Station (3). It was found that when blueberry plants were watered with leachate from sawdust, growth was doubled, as compared with a three fold increase in growth when a two-inch mulch was used. When the leachate was boiled before applying, there was very little increase, thus suggesting that the favorable substance or substances may be an enzyme or enzyme-like material which is destroyed or inactivated by heat.

With respect to size of wood fragments in their comparative effects, Salomon (18) found that large chips (>¼") reduced yields more than did fine chips, due to the presence of undecomposed wood particles. Likewise, in an experiment at Geneva, N.Y., (20) which included a comparison of woodchips with sawdust, second crop yields of tomatoes (1953) were lower with chips than with sawdust. This was as true when the materials were used as a mulch as when plowed in. However, in the case of the succeeding cabbage crop (1954), the differences between chips and sawdust were less distinct.

In attempting to evaluate chips for soil improvement, it is necessary to take cognizance of the cost of supplemental nitrogen which is needed if a crop is to be grown the same year the chips are applied. If we assume that nitrogen is required at the rate of 1 pound for each 100 pounds of dry chips, 10 tons or roughly 66 cu yds of dry chips per acre will require 200 pounds of N or 600 pounds of ammonium nitrate costing approximately $30 for each acre.

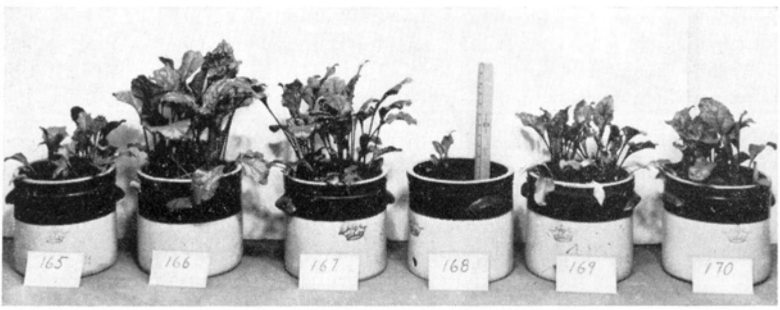

Figure 9. Effect of the very high rate (40 T/A) of oak-hickory woodchips, previously soaked in ammonium nitrate solutions of varying concentration on the growth of the fourth crop (second beet crop). 165 = weak solution, 350 ppm N; 166 = medium, 2800 ppm; 167 = strong, 7000 ppm; 168 = very strong, 35000 ppm; 169 = water only; 170 = check (no chips). Cheshire loam soil. (Compare with Figure 4.)

Several solutions are suggested. The cheapest and probably most satisfactory all around solution is to use the chips in the barn as bedding. A second solution would be to confine chips treatments to those fields upon which a legume is to be grown.

A third alternative is to use an inexpensive source of nitrogen such as digested sewage sludge. In some localities chicken manure is available for the hauling, and one could hardly find a better combination than chips or sawdust, and chicken manure.

Another alternative is to make lighter applications of chips, as proposed by Waring (22). In this case one would need to choose between small benefits and low cost on the one hand, and relatively greater benefits at higher costs on the other. This work has shown that the 40-ton rate was not too high; in fact, between the first and seventh crops in the greenhouse, it was the 40-ton rate which had the greatest benefit. Considering cartage and spreading costs, the higher application may prove to be the most economical in the long run.

It might be less expensive to treat the chips with nitrogen solution prior to applying them to the soil. Some preliminary tests showed that if chips were soaked in a solution containing between 1000 and 3000 ppm of nitrogen, all possibility of N deficiency was overcome (Figure 9).

It would appear that the cost of chips or sawdust treatment would compare favorably with that for other organic matter. When obtainable free at the treatment plant, digested sewage sludge is perhaps the cheapest source of organic matter and it contains considerable nitrogen (1-3%).

Summary and Conclusions

Studies were conducted over a five-year period to determine the effectiveness of woodchips (and sawdust) for soil improvement. In most cases the chips were applied only once and worked into the soil, with and without extra nitrogen. Crop yields or plant growth was measured and various tests made on the soils. The work was done in greenhouse pots, in outdoor soil frames, and on field plots.

These studies show that woodchips (or sawdust): (1) had no appreciable effect on soil acidity nor were they toxic to plants aside from the temporary nitrogen deficiency. (2) Chips had a modest but generally favorable effect on soil structure, organic matter content, and associated soil properties. (3) When fresh, chips almost invariably reduced first crop growth, and were not consistent in their effect on succeeding crops. (4) When supplemented with sufficient nitrogen or when composted before applying, chips did not decrease first crop yields, and they generally increased yields of succeeding crops. (5) Chips are probably more effective on sandy soils than on loams, although very coarse-textured soils may become excessively loose and open the first year or two, unless the chips are first composted. (6) Birch chips decomposed more rapidly than either oak or pine and would require the most nitrogen to prevent deficiencies. Pine decomposition was slowest of the three and required the least amount of nitrogen. In general, pine chips were more effective than oak or birch in improving the soil.

It is concluded that woodchips, sawdust, or other types of wood fragments are beneficial to the soil, particularly where the texture is sandy loam or coarser. (Their effects on fine-textured soils have not been studied in this work but there is evidence from the literature of marked improvement in porosity and friability as a result of sawdust or shavings applications.) Repeated use of chips every few years, in conjunction with good soil management, would undoubtedly result in appreciable and permanent soil improvement.

Generally the incorporation of fresh chips has no detrimental effect on the crop if sufficient nitrogen is present or provided. A safer practice, however, is to apply the chips ahead of a green manure crop, preferably a legume, or in any event to allow about a year interval between application and seeding or planting of the main crop. Other good ways to use wood fragments which may be preferable under some conditions are: (a) as bedding in the barn followed by field application of the manure; (b) as a mulch on row crops, eventually working the partially decomposed material into the soil; or (c) after adequately composting the chips with other organic materials. Naturally well-rotted pure chips or sawdust is safe material to use under almost any condition.

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