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Soil Management for Vegetable Production on Honeoye Soil with Special Reference to the Use of Hardwood Chips

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Soil management practices for satisfactory production of specific crops or combination of crops can often be adjusted for improvement from the standpoint of sound scientific principles and economics. Recognition of the management problem involved is the obvious first step to be taken.

Brady, Struchtemeyer, and Musgrave (1957) have discussed soil management problems in the Northeast. Referring to the dairy and cash crop area of New York, where a relatively high proportion of cropland is devoted to growing vegetables, they stated, ". . . lack of fertilizer was seldom the limiting factor in growing vegetables on the better farms." But they also said that maintenance of organic matter had become a problem where cash crops occupy much of the land.

The difficulty of maintaining a supply of decomposing organic matter in soils of another vegetable-producing area in the East has been stressed by Hanna and Oben-chain (1957). They particularly emphasized the value of rotations and cover crops, and, with respect to the effects of a sod-based rotation on soil moisture availability in that area, they reported, "Yields of vegetables and potatoes grown in a three year rotation with one year of sod without irrigation equaled the yields from continuous cultivation of these crops with irrigation in dry years."

Packing and crusting of the soil were mentioned as serious consequences of an insufficient amount of organic matter. Increased erosion damage may also result from deterioration of the soil's physical condition and from increased soil exposure under row crops.

The following quotation from Flack and Cline (1954) stresses the beneficial effects of an adequate level of soil organic matter. "Every farmer should be concerned with the amount of organic matter in his soils. It is the storehouse of N in the soil. It holds K and Ca against leaching and slowly releases them to crops. It is one of the principal sources of energy for many beneficial kinds of organisms. It is one of the principal agents of granulation, and by improving soil structure, it helps to regulate the water and air in the soil. It also holds the soil against erosion, thus conserving it for the future. These and other effects of organic matter make it highly desirable to maintain an adequate level in our soils."

A good balance between row, grain, and hay crops may still exist where vegetable and other cash crops are only a part of regular dairy farming. As the shift to intensive cropping progresses, rotations may no longer be sod-based and farm manure is apt to be scarce. Evaluation of alter-

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native systems of soil management, including the use of hardwood chips, was started in New York in 1951 and terminated in 1966. Sweet corn *(Zea mays),* beans *(Phaseolus vulgaris),* tomatoes *(Lycopersicon esculentum),* cabbage *(Brassica oleracea),* and peas *(Pisum sativum)* were grown as vegetable crops that occupy significant acreages in New York.

It is the purpose of this bulletin to present and discuss the results of this evaluation of management systems over a 15-year period. In an earlier publication, Free (1956) summarized results for some of the systems over the first 5 years.

Materials and Methods

General

The experiment was located on the soil conservation research farm near Marcellus, N.Y., about 15 miles southwest of Syracuse. This is at the eastern edge of the area classed as combination dairy and cash crop by Brady *et al.* (1957). The soil is Honeoye silt loam, an important, well-drained, productive, high-lime Hapludalf developed fromi glacial till derived largely from limestone and shale (Soil Survey Staff, 1960). The degree of past erosion was moderate and land slopes were within the range of 6 to 10 per cent. Available soil phosphorous was low. Plot areas had been in sod for several years. The purpose was maintenance or improvement of soil physical condition rather than any attempt to rebuild it from a low level.

A randomized block design with 3 replicates was used for mainplot treatments. Plots were 36 feet wide, up and down slope, by 40 feet across slope. Plowing and planting was across slope at a slight grade. Narrow unplowed areas were left between plots up and down slope, with wider unplowed aisles between plots across the slope. Row drainage and those areas left in sod provided some insurance against runoff washing onto or across neighboring main plots.

Main-plot Management Systems

For soil management systems 1 through 6 (table 1), vegetables were grown for the 15-year period in a 5-year

Table 1. *Main-plot treatments*

	Treatments			Crops by years§				
No.	Cropping system*	Organic amendment†	Cover crop‡	1951 1956 1961	1952 1957 1962	1953 1958 1963	1954 1959 1964	1955 1960 1965
1	C	O	O	SC	B	T	C	P
2	C	PU	O	SC	B	T	C	P
3	C	TD	O	SC	B	T	C	P
4	C	O	CC	SC	B	T	C	P
5	C	PU	CC	SC	B	T	C	P
6	C	TD	CC	SC	B	T	C	P
7	I	O	CC	SC	Br	Br	C	P
8	I	PU	CC	SC	Br	Br	C	P
9	SA1	O	CC	SC	A	T	C	P
10	SA1	PU	CC	SC	A	T	C	P
11	SA2	O	CC	SC	A	A	C	P
12	SA2	PU	CC	SC	A	A	C	P
13	SAB	O	CC	SC	AB	AB	C	P
14	SAB	PU	CC	SC	AB	AB	C	P
15	C	O	O	Same as No. 1 above except started 1956				
16	C	O	O	Same as No. 1 above except started 1961				

* Cropping system
C — Continuous vegetables
I — Intermediate; Sweet corn – grass in rows for seed 2 years – cabbage – pea
S — Sod-based: A1 sweet corn – alfalfa – tomatoes – cabbage – peas
A2 sweet corn — alfalfa 2 years — cabbage — peas
AB sweet corn – alfalfa and brome 2 years – cabbage – peas

† Organic amendments
- O — None
- PU — Hardwood chips plowed under
- TD — Hardwood chips top-dressed

‡ Cover crops
- O — None
- CC — Cover crops following vegetables

§ Crops
- SC — Sweet corn
- B — Dry beans
- Br — Bromegrass for seed
- A — Alfalfa for hay
- AB — Alfalfa and bromegrass for hay
- C — Cabbage
- P — Peas with alfalfa and clover underseeded
- T — Tomatoes

rotation with combinations of hardwood chip amendments and cover crops as variables. The cover crop seeded at the last cultivation was annual ryegrass (Lolium multiflorum) 1951-1954 and field bromegrass (Bromus arvensis) thereafter. Ryegrass was subject to considerable winter killing but bromegrass was not.

For systems 7 through 14, beans or beans and tomatoes were replaced by sod crops seeded immediately following sweet corn, with or without wood chips. Cover crops were used for vegetables in sod-based rotations. Systems 15 and 16 were the same as treatment 1, except that they were broken from original sod at later 5-year intervals.

Residues were left on or returned to plots for plowing under. Peas were underseeded with a mixture of alfalfa and clover to be plowed under for sweet corn the following year.

The annual rate of wood chip use was the same for all treatments receiving wood chips, 10 tons per acre wet weight annually, which was equal to about 7 tons dry weight. This was enough to barely cover the soil. The chips included wood particles about *Vi* inch in size, bark, twigs, and sometimes leaves. They were home-chipped from the hardwood species maple *{Acer)*, elm *(Ulmus)*, and ash *(Fraxinus)*. The machine used was able to chip trees and limbs up to 6 inches in diameter.

Basic mineral fertilizer treatments for all crops are shown in tables 2 and 3. The rates of mineral fertilization (F) given in table 2 were intended to correspond with rates recommended by the Department of Vegetable Crops at Cornell University. Each main plot, when in vegetable crops, was split to receive 4 fertilizer treatments: F as shown, ¼F, F + N, and ¼F + N, where N represents 100 pounds per acre additional N as ammonium nitrate, ¼F was applied at planting; ¾F and supplemental N were plowed down. The locations of treatments were randomized at the start and held unchanged for the duration of the experiment. This gave 4 split-plot treatments, designated F, ¼F, F + N, and ¼F + N.

The purpose of including these fertilizer and nitrogen treatments on a split-plot basis was to study the expected interactions with main-plot treatments, particularly with respect to those with and without woodchip amendments.

Table 2. *Basic rates of fertilization (F) for vegetable crops*

Crop	N	P_2O_5	K_2O
		lbs/acre	
Sweet corn (SC)	30	60	30
Beans (B)	30	60	30
Tomatoes (T)	80	160	80
Cabbage (C)	100	200	100
Peas (P)	30	60	30

Based on data in tables 1, 2, and 3 and an estimate of the principal plant nutrients N, P, and K supplied by woodchips, information on both the range of amounts of these nutrients in this experiment and on the proportion supplied by woodchips may be found in appendix table 1.

Crop Yields

The size of areas from which crop samples were harvested from each subplot and weighed for determination of yields of marketable products ranged from 6 to 10 feet wide, depending on row width, by 15 feet long in direction of row. This left border- or buffer-cropped areas around each plot used for yield determination.

There were multiple pickings or harvests of ripe tomatoes and sweet corn and either 2 or 3 cuttings per year of hay crop. Beans, cabbage and peas had only single harvest dates.

Only in 1953, when the crop was tomatoes, was there any formal grading of harvested crop. In 1963, only, green fruit left on the vine at the end of the growing season was weighed.

Amounts of organic materials turned under in the form of crop residue, winter cover crops, or the green manure crop seeded with peas were not routinely determined. There were determinations of some of these in 1956, 1959, and 1963 and these results will be discussed. Also, some effects of selected management practices in this experiment on soil tests and on yields and composition of cover crops have been reported elsewhere by Ram and Zwerman (1960, 1961).

Chemical Soil Tests

Before this experiment was started in 1951, samples of the plow layer were taken from all main plots; the mean levels of soil organic matter and aggregate stability were 4 percent and 80 percent respectively. Those subplots with the extremes of fertilizer treatments, F + N and ¼ F, were sampled before plowing in 1956, 1961, and 1966 — at the end of each 5-year rotation. The Cornell Soil Test Laboratory used these samples for determination of pH, organic matter, total N, and "available" P and K. Grewel-ing and Peech (1960) have described the methods for these chemical soil tests.

Table 3. *Fertilization for forage crops when planted**

Crop	N	P_2O_5	K_2O
		lbs/acre	
Alfalfa (1 year)	0	80	80
Alfalfa (2 years)	0	120	120
Alfalfa and bromegrass	0	120	120
Bromegrass for seed†	50	100	50

* Banded below seed at planting.
† 40 lbs/acre additional N side-dressed each spring.

Aggregate Stability

From the start of the experiment to the fall of 1958, the subplots of the extremes of fertilizer treatments were sampled 7 times for determination of wet aggregate stability. Starting with the fall of 1958, they were sampled each fall and each spring. Wet aggregate stability of samples allowed to air-dry was determined by the 2-screen method described by Bryant, Bendixen, and Slater (1948). Results were corrected for material > 2 mm in size.

Bulk Density and Undecomposed Organic Matter

From 3 to 6 undisturbed soil cores 3 inches in diameter and 3 inches deep were taken with a Uhland sampler (Uhland and O'Neal 1951), before plowing in 1956, 1961, and 1966 from the surface of F + N and ¼ F subplots of selected main-plot treatments. These were dried at 105°C. Bulk densities were calculated from soil weights and volumes corrected for material > 2 mm. These same core samples were also used for determination of undecomposed organic material in the soil. Separation of this material, which included roots, crop residues, and woodchips, was accomplished by a flotation process.

Indices of Biological Activity

The relationship of earthworms to soil productivity received much attention in the 1940's. During the early years of this experiment, it was observed that earthworm populations differed under the various soil management systems. Indices of these populations were obtained from counts of earthworms exposed and readily visible during plowing in 1954, 1955, 1956, and 1959. Enough estimates of total populations in 9-inch diameter soil cores were determined to establish the validity of the furrow counts as indices of populations.

Also, in May 1955, after peas had been planted on all plots, small maple sticks of known oven-dry weight were inserted in the plow layer of the F + N and !4 F subplots of all main plots. A record of exact locations was kept and approximately one year later the sticks were carefully removed, cleaned, and dried. Losses of weight provided indices of the general biological decomposition activity in the different plots and subplots.

Soil Moisture

Soil moisture was not measured routinely, but there were several detailed studies of it. Before 1962, moisture was determined gravimetrically on auger samples. Results of soil moisture measurements starting in 1962 using an N/C Model P 21 surface neutron gauge and 2800 sealer will be presented and discussed in some detail.

In late fall 1961, soil samples for determination of moisture retention curves were taken from the plow layer of all subplots of treatments 1, 3, 4, and 12. Undisturbed core samples and commercially available suction plate and pressure membrane apparatus were used.

Soil Temperature

Soil temperature data were obtained by manual meas-urements with a dial thermometer. In addition, data were obtained on the depth and nature of frost penetration. This was judged by the resistance encountered in driving a pointed rod into the soil.

Erodibility

At the end of formal operation of this experiment, all main-plot replicates of treatments 1, 3, 13, 14, and 15, and a plot freshly broken from sod were fallowed and seedbeds were prepared in both 1966 and 1967 as if a corn crop was to be planted. A boom-type rain simulator (Swanson, 1965) was used for determination of erodibility as a short-term residual of past management.

Pairs of plots, each 12 feet wide by 35 feet long, were located on the main plots. Simulated rain was applied in 1966 and 1967 at an intensity of 2 ½ inches per hour in 3 separate 30-minute "storms" closely following each other on the same day. The expectancies of single natural storms having erosion potentials equal to 1 such storm, 2 such storms combined, or 3 such storms combined are about once in 2, 10, or 40 years, respectively, in Central New York (Wischmeier and Smith, 1965). An erosion potential index equal to 3 such storms combined has a 50 percent probability of occurring as an annual total.

Rainfall

Precipitation data, May through October, for each of the 15 years 1951-1965 are summarized in appendix tables 2 and 3. Overall rainfall deficiencies were marked in 1954, 1959, 1962, 1964, and 1965. Above-normal precipitation occurred in 1951, 1956, and 1958. Planting and harvesting dates for various crops are summarized in appendix table 4, and may be directly compared with 4-week periods of low rainfall shown in appendix table 3.

Results — Vegetable Crop Yields

Three-year mean yields by main-plot treatments for each vegetable crop are presented in table 4. Results of analysis of variance of the data are given in table 5. Each yield is the mean of 36 values (3 replicates X 3 years X 4 subplot treatments). Overall block by mainplot treatment variances were used to determine the significance of main-plot treatment (T) for each crop (table 5).

To determine significance of superiority or lack of it for paired main-plot treatment comparisons, a nonparametric rank test was used for main-plot treatments 1-6. Treatment comparisons extended over the 15-year period, providing 3 plots X 3 years, or 9 paired comparisons for 5 crops. Individual subplot yields were not paired for these comparisons.

Table 4. *Vegetable yields — 3-year means*

Treatment* No.	Coded	Corn	Beans	Tomatoes	Cabbage	Peas
		tons/acre	cwt/acre	tons/acre	tons/acre	tons/acre
1	C — O — O	5.2	19.3	18.8	15.8	2.4
2	C — PU — O	5.1	22.4	20.2	17.4	2.5
3	C — TD — O	4.9	23.7	21.5	21.2	2.6
4	C — O — CC	4.7	22.1	16.6	17.9	2.4
5	C — PU — CC	5.1	24.1	17.5	17.1	2.8
6	C — TD — CC	4.8	22.8	19.9	18.5	2.6
7	I — O — CC	5.4	..	..	16.7	2.5
8	I — PU — CC	5.4	..	..	16.9	2.7
9	SA_1 — O — CC	4.8	..	15.8	16.7	2.2
10	SA_1 — PU — CC	4.8	..	17.2	18.0	2.7
11	SA_2 — O — CC	4.9	..	..	15.8	2.3
12	SA_2 — PU — CC	4.8	..	..	15.8	2.4
13	SAB — O — CC	4.3	..	..	15.1	2.4
14	SAB — PU — CC	5.4	..	..	17.1	2.5
LSD 5%		NS	2.7	NS	2.0	0.3

* See table 1 for key to treatments.

On this basis, treatment 3 involving wood chips top-dressed without a cover crop was superior to treatment 1 without wood chips at the 1% level. Treatment 2 involving wood chips plowed down without a cover crop was superior to treatment 4, which had a cover crop but no wood chips, at the 5% level. These were the only significant indications of overall superiority in the 15 possible comparisons of the 6 treatments. It should be emphasized that overall superiority does not imply equal degrees of superiority for each crop.

The same rank test was used for comparisons of yields under treatment 1, involving 15 years of continuous vegetables without wood chips or cover crop, with those under treatments 15 and 16 involving 10 and 5 years of continuous vegetables, respectively. In this case, yields for individual subplots were used to provide 12 paired yields for each year or crop, and 60 paired yields were possible for each. The possible comparisons are summarized as follows:

Period and treatment comparison	Significance of overall yield superiority of first *vs* second listed
1956–1960	
15 *vs* 1 (1st rotation after sod *vs* 2nd)	Not significant
1961–1965	
16 *vs* 15 (1st rotation after sod *vs* 2nd)	Not significant
15 *vs* 1 (2nd rotation after sod *vs* 3rd	Approaches significance at 5 percent level
16 *vs* 1 (1st rotation after sod *vs* 3rd)	Significant at 5 percent level

Table 5. *Results of analyses of variance of vegetable yield data*

Variance	Corn	Beans	Tomatoes	Cabbage	Peas
Main-plot treatment (T)	NS	*	NS	**	**
Interaction T X year (Y)	NS	NS	**	**	**
Fertilizer level (F)	**	**	**	**	**
Interactions F X Y	**	*	NS	**	**
F X T	*	NS	*	NS	NS
F X Y X T	NS	NS	NS	NS	NS
Nitrogen (N)	**	**	NS	*	*
Interactions N X Y	*	NS	NS	*	NS
N X T	**	NS	NS	NS	NS
N X Y X T	*	NS	NS	NS	NS
N X F	NS	NS	NS	*	NS
N X F X Y	*	NS	NS	NS	NS
N X F X T	NS	NS	NS	NS	NS

* Indicates item significant at 5% level.
** Indicates item significant at 1% level.
NS Indicates lack of significance at 5% level.

Yield levels were markedly affected by the fertilizer levels (F and ¼ F). However, the trends with increasing number of rotations, not shown separately, were similar. As in the comparisons for treatments 1 through 6, overall superiority does not imply equal degrees of superiority for each crop. Results were influenced more by trends for beans and cabbage than by trends for the other crops.

Details of crop yield by years and by fertilizer and nitrogen split-plot treatments are not presented in this bulletin, but significant effects, particularly those involving main-plot treatments will be presented under headings of individual crop to follow.

Sweet Corn

Three-year mean yields for the 14 main-plot treatments were not significantly different. Also, the interaction of treatments by years was not significant. Yields for years 1951, 1956, and 1961 over all 14 treatments were 4.4, 5.9, and 4.7 tons per acre of marketable corn in husks.

Subplot yields were significantly affected by nitrogen and fertilizer levels, and the interactions of both with main-plot treatments were also significant. Extra N and full-rate fertilization F compared with *Vi* F increased yields by 6 and 10 percent respectively.

Much of the meaning of the significant interactions involving N and main-plot treatments is made clear in table 6. Only with additional N over base fertilization did mean yields with woodchips exceed those without woodchips. The effect of omitting extra N was greatest in 1956. For treatments 7, 11, and 13 without woodchips, overall mean yields were slightly depressed by additional N, and the overall effect without woodchips was negligible.

The effect of full-rate fertilization compared with ¼ full rate was to increase overall yields by 6, 7, and 17 percent for the years 1951, 1956, and 1961, respectively. Averaged over the 3-year period, effects of fertilizer level (F compared to ¼ F) ranged from 16 to 21 percent increases for treatments 1, 9, 13, and 14 to a decrease of 4 percent for treatment 4. Increases for other treatments ranged from 5 to 9 percent.

Beans

Three-year mean yields for main-plot treatments 2 through 6 were all greater than the yield for check treatment, number 1. The increase was significant for treatments 3 and 5. The treatment by year interaction was not significant. Mean yields of all main plots for the years 1952, 1957, and 1962 were 21.2, 23.6, and 21.5 cwt per acre, respectively.

The yield increases resulting from higher levels of both nitrogen and fertilizer were significant, amounting to 4 and 15 percent respectively. The interaction of fertilizer level and years was significant. The overall yield increases asso-l ciated with the higher fertilizer rate were 10, 17, and 19 percent, respectively, for the years 1952, 1957, and 1962. The interactions of subplot with main-plot treatments were not significant.

Table 6. *Yields of sweet corn as affected by main-plot treatments with and without hardwood chips, and subplot treatments with and without extra nitrogen fertilization*

Treatment	Mean yields			
	1951	1956	1961	3-year mean
	tons per acre			
All plots with woodchips				
with extra N	4.6	6.3	5.1	5.3
without extra N	4.3	5.4	4.6	4.8
All plots without woodchips				
with extra N	4.4	6.1	4.5	5.0
without extra N	4.4	6.0	4.6	5.0

Tomatoes

Three-year mean yields for main-plot treatments were not significantly different, but the treatment by year interaction was highly significant. Mean yields for all main-plot treatments for years 1953, 1958, and 1963 were 15.6, 22.4, and 17.4 tons per acre, respectively.

In 1953, yields for treatments 3 and 6 involving top-dressed wood chips were significantly greater than the yield for check-plot treatment 1. In 1958, the effect of main-plot treatment was not significant. This may be related to more than normal rainfall in 1958. In 1963, the yield for treatment 3 was significantly greater than the yield for treatment 1, while yields for treatments 9 and 10, involving a sod crop with and without wood chips, were significantly less. The low yields for treatments 9 and 10 in a dry year may be associated with moisture use by alfalfa, in 1962 and early in 1963.

Subplot yields were not significantly affected by additional N, although the overall trend was toward decreased yields at both levels of fertilizer and for most main-plot *i* treatments.

Subplot yields were significantly affected by fertilizer level; the mean benefit from full fertilization F compared with !4 F amounted to 12 percent. The interaction with main-plot treatments was significant; the increases from full fertilization ranged from a low of 11 percent for treatment 4 to a high of 14 percent for treatments 1 and 9.

The effect of main-plot and fertilizer treatments on ripening, quality of fruit, and total fruit set received specific attention only in 1953 and 1963. In 1953 the effects of main-plot treatments on yields for individual harvests or pickings was highly significant but of limited practical importance. By August 20, percentages of total harvest picked ranged from 27 to 37 percent. Treatments 1, 3, and 6 ranged from 27 to 29 percent within this range. By August 27, however, percentages ranged only from 70 to 75 percent, with no well-defined pattern among treatments.

Also in 1953, the effects of fertilizer treatments on pickings was highly significant. By August 20, ripe fruit picked from subplots with the high fertilizer treatment was only 8 percent greater than that picked from the low or ¼ F fertilizer treatment. The corresponding percentage for subsequent pickings was 35 percent.

In 1953, some grading of harvested fruit was done. ' There was a significantly lower percentage (44%) of top-grade fruit for the number 1 check treatment than for any other treatment (range 52-60%). Effects of subplot fertilizer treatments on quality were not significant.

Total fruit set was particularly heavy in 1963, and by the end of the season more than the usual quantity of green fruit was left on the vines. The amount of this green fruit measured as means of high and low fertilizer levels ranged from about 7 tons per acre for treatments 1 and 9 to about 13 tons for treatments 3, 5, and 6. About 62 percent of these amounts were for the high fertilizer treatment.

For ripe fruit yields in 1963, the interactions of main plot treatments and pickings, and fertilizer level and pickings, were both highly significant. By September 23, from 38 to 44 percent of total ripe fruit had been harvested from treatments 1, 2, 9, and 10 compared with 28 to 32 percent for treatments 3, 4, 5, and 6. For first, second, third, and fourth harvests respectively, yields of the low fertilizer treatments were 90, 79, 73, and 64 percent of those for high-rate fertilization.

Cabbage

Three-year mean yields for treatments 3, 4, 6, and 10 were significantly greater than the mean yield for check treatment 1. The interaction of main-plot treatments with years was highly significant. Mean yields over all treatments for years 1954, 1959, and 1964 were 13.8, 18.0, and 19.5 tons per acre respectively.

These mean yields are satisfactory for the years they represent, since rainfall for the periods July through September ranged from only 64 to 71 percent of normal. Hoecher (1942) found that mean yields were 13 percent less than normal when rainfall for July, August, and September ranged from 70 to 90 percent of normal.

All three of the years were dry, and treatments 3 and 6 involving top-dressed wood chips were superior to the check by amounts at or well above significant levels. In 1964, yields for all treatments except 9 and 13 were significantly greater than check.

Both extra N and full fertilization (F) produced yields higher than those of the ¼F level. Yields were increased 8 percent by extra N and 28 percent by full fertilization. Extra N above full fertilization increased yields only 2 percent. Interactions of split-plot treatments with main-plot treatments were not significant.

The interactions of both extra nitrogen and the two fertilizer levels with years were significant. The yield increases associated with extra N were 2, 6, and 4 percent respectively for 1954, 1959, and 1964. Increases associated with F fertilization levels compared with ¼ F were 26, 35, and 23 percent for these years.

Peas

| Rainfall was below normal for May and **June in** 1955 and 1965 but was above normal in 1960. Three-year mean yields for treatments 5, 8, and 10 involving wood chips plowed down were significantly greater than the yield for check treatment 1. The main-plot treatment by year interaction was also significant. Mean yields over all treatments for the years 1955, 1960, and 1965 were 1.8, 3.2, and 2.6 tons per acre, respectively.

In 1955, one of the dry years, yields from main-plot treatments did not differ significantly from those of the check. In 1965, the other dry year, only treatment 5 yielded significantly more than the check. Treatment 13 yielded significantly less. In the wet year, 1960, treatments 3, 5, 6, 7, 8, and 14 yielded significantly more than the check. All but two of the wood chip treatments without alfalfa in the rotation are included, and treatment 14 had both wood chips and alfalfa.

Extra N fertilization significantly reduced yields by 4 percent. The standard fertilization treatment (F) gave an average 13 percent greater yield than Vi F, but the increase was only 2 percent in the wet year 1960. The increase was more than 20 percent in 1955 and 1965. Interactions with main-plot treatments were not significant.

Hay and Grass Seed Yields

Hay yields for treatments 9 through 14 are presented in table 7. The effect of main-plot treatments was slight. Yields of treatment 14 with wood chips exceeded those of 13 without wood chips at the 10 percent probability level.

The residual effects of nitrogen and fertilizer levels used as split-plot treatments for vegetables but not for hay were significant. The full fertilization and high nitrogen levels for vegetables resulted in average increases of hay yields amounting to 10 and 4 percent repectively. Interactions with main plot treatments were not significant.

Smooth bromegrass for treatments 7 and 8 was seeded in rows following sweet corn harvests in 1951, 1956, and 1961. The seeding date was late in 1956. Seeding failures, loss of stands, and quackgrass contamination made seed harvests possible only in 1952, 1953, and 1958 when yields of seed for the best treatments were 489, 561, and 687 pounds per acre, respectively. Pardee and Lowe (1963) reported that smooth bromegrass seed yields are extremely variable in New York.

Table 7. *Hay yields (oven-dry basis)—3-year means*

Treatment* No.	Treatment* Coded	First year	Second year
		tons/acre	
9	SA_1 — O — CC	2.5	—
10	SA_1 — PU — CC	2.4	—
11	SA_2 — O — CC	2.5	3.5
12	SA_2 — PU — CC	2.6	3.7
13	SAB — O — CC	2.5	3.5
14	SAB — PU — CC	3.0	4.0

* See Table 1 for key to treatments.

Green Manure and Cover-crop Yields

Yields of winter cover crops and of the legumes seeded with peas were not determined routinely. However, in mid-September 1960, one set of samples of the legume under-seeding was taken. Yields ranged from 1.7 tons of dry matter per acre for treatment 1 to 2.4 for treatment 3. The treatments with yields significantly greater than that for check treatment number 1 were 2, 3, 6, 10, and 14. Treatments with yields significantly lesss than check were 11, 12, and 13. The yield benefit from high-level fertilization as the split-plot treatment for vegetables was 28 percent compared with a negligible 3 percent for high-level N. Interactions with main-plot treatments were not significant.

On May 26, 1959, just before plowing for cabbage, samples of above-ground growth of cover crops at high (F + N) and low (Vi F) fertilizer levels were taken from plots of treatments 4, 5, 6, 9, 10, 11, 12, 13, and 14. Mean yields for high and low fertilizer levels were 0.86 and 0.71 ton per acre respectively. This difference of 21 percent was highly significant. Mean yields for main-plot treatments ranged from a low of 0.49 for treatment 6 to a high of 1.03 for treatment 9, but this difference was not statistically significant for this one sampling. A low yield for treatment 6, however, does agree with observations made at other times. Cover crops were generally seeded in July in corn, beans, and tomatoes and in August in cabbage.

In 1963, after all ripe and green tomatoes had been removed, 10-vine samples were taken from each fertilizer subplot for treatments 1, 2, 3, 4, and 9 and were oven dried at 80°C. The effects of main-plot treatments and fertilizer level on dry weights were significant, but the interaction was not. The mean dry weight of the 10-vine sample from treatment 3 was 4.0 pounds compared with 2.5 to 3.0 pounds for the other samples. The mean weights for samples from high and low fertilization levels were 3.4 and 2.7 pounds respectively.

Modification of Soil Properties

Chemical Soil Tests

Soil samples were taken in 1956, 1961, and 1966 from the 0-6-inch depth of selected split-plot fertilizer treatments on all main plots. Results of determinations of soil pH, organic matter, total nitrogen, "available" phosphorous and potassium are presented in tables 8 through 12 for the 1966 samples only. Corresponding data for the 9-12 inch depth are also presented in these tables.

In tables 8 through 12, some of the results for the 0-6-inch depth are followed with the letters D or I. This indicates that those test values for the 3 years of sampling, although not presented for 1956 and 1961, progressively decreased (D) or increased (I).

pH Values

There is a consistent tendency at both depths for those *m* treatments receiving hardwood chips to have slightly lower pH values than those for corresponding treatments without chips (table 8). Mean values at the 0-6-inch depth for the chip treatments ranged from 6.9 to 7.1 compared with 7.0 to 7.3 for the no-chip treatments.

Less marked but still significant is the tendency for slightly lower pH values under the F + N fertilizer treatment compared with the V4 F treatment. The interaction of main-plot treatment with fertilizer level was not significant.

As would be expected of this high-lime soil, pH values for the 9-12-inch depth are consistently higher than for the 0-6-inch depth.

Organic Matter

At the 0—6-inch depth, the highly significant effect of hardwood chip amendments is apparent, with mean test values for these treatments ranging from 4.9 to 5.8 percent compared with a range of 3.6 to 4.2 percent for nonchip treatments (table 9).

Values for treatments which included cover or sod crops without woodchips, numbers 4, 7, 9, 11, and 13 were all

Table 8. *Results of pH soil tests — 1966*

Treatment†		0–6-inch depth		9–12-inch depth	
No.	Coded	F + N	¼ F	F + N	¼ F
			pH value		
1	C — O — O ..	7.2	7.3	7.4	7.5
2	C — PU — O ..	7.0 D	7.2	7.2	7.3
3	C — TD — O ..	6.8	7.0 D	6.9	6.9
4	C — O — CC ..	7.1 D	7.3 D	7.3	7.2
5	C — PU — CC ..	7.0 D	7.1 D	7.2	7.3
6	C — TD — CC ..	7.0 D	7.1	7.1	7.4
7	I — O — CC ..	7.1	7.2	7.3	7.3
8	I — PU — CC ..	6.9	6.9 D	7.2	7.2
9	SA_1 — O — CC ..	7.3	7.3 D	7.3	7.3
10	SA_1 — PU — CC ..	6.9	7.1 D	7.1	7.3
11	SA_2 — O — CC ..	7.0	7.1 D	7.3	7.4
12	SA_2 — PU — CC ..	6.9	7.0 D	7.2	7.3
13	SAB — O — CC ..	7.0 D	7.1 D	7.3	7.3
14	SAB — PU — CC ..	6.9	7.0 D	7.2	7.3
15	C — O — O ..	7.2	7.3	7.4	7.5
16	C — O — O ..	7.2	7.3	7.4	7.5
	LSD @ 5%	0.2		0.2	
Significance:					
	Main-plot treatment (T)	**		**	
	Fertilizer level (F)	**		*	
	Interaction (T X F) ...	NS		NS	

† See Table 1 for key to treatments.
* Significant at 5% level.
** Significant at 1% level.
NS Not significant at 5% level.

Table 9. *Results of soil organic-matter tests — 1966*

Treatment†		0–6-inch depth		9–12-inch depth	
No.	Coded	F + N	¼ F	F + N	¼ F
		percent			
1	C — O — O ..	3.8 D	3.3 D	2.1	1.8
2	C — PU — O ..	5.2	4.9	3.5	2.8
3	C — TD — O ..	5.1	5.7	2.4	2.5
4	C — O — CC ..	4.2 D	4.2 D	2.3	3.4
5	C — PU — CC ..	5.4	5.4 I	2.7	3.3
6	C — TD — CC ..	5.4	4.4 D	1.9	2.2
7	I — O — CC ..	3.9 D	4.0 D	2.2	3.0
8	I — PU — CC ..	5.3	5.3	2.5	2.6
9	SA_1 — O — CC ..	4.1 D	3.6 D	2.6	2.3
10	SA_1 — PU — CC ..	5.1	4.9 D	2.7	2.2
11	SA_2 — O — CC ..	4.2	4.2	2.3	2.3
12	SA_2 — PU — CC ..	5.3	5.4	2.4	2.5
13	SAB — O — CC ..	4.5	4.0 D	2.7	2.5
14	SAB — PU — CC ..	5.9 I	5.7 I	2.5	2.4
15	C — O — O ..	3.9 D	3.4 D	2.9	2.0
16	C — O — O ..	3.9	3.8	1.9	2.3
LSD @ 5%		0.7			
Significance:					
Main-plot treatment (T)		**		NS	
Fertilizer level (F)		*		NS	
Interaction (T X F) ...		NS		NS	

† See Table 1 for key to treatments.
* Significant at 5% level.
** Significant at 1% level.
NS Not significant at 5% level.

Table 10. *Results of determinations of total soil nitrogen 1966*

Treatment†		0–6-inch depth		9–12-inch depth	
No.	Coded	F + N	¼ F	F + N	¼ F
		percent			
1	C — O — O ..	0.18 D	0.16 D	0.14	0.15
2	C — PU — O ..	.23 I	.23	.17	.14
3	C — TD — O ..	.24	.29 I	.15	.13
4	C — O — CC ..	.22	.21	.14	.18
5	C — PU — CC ..	.24	.24	.17	.16
6	C — TD — CC ..	.25 I	.23	.12	.13
7	I — O — CC ..	.19 D	.20	.13	.16
8	I — PU — CC ..	.25 I	.23	.15	.18
9	SA_1 — O — CC ..	.22	.19 D	.18	.14
10	SA_1 — PU — CC ..	.24	.23 I	.16	.13
11	SA_2 — O — CC ..	.23	.22 I	.13	.14
12	SA_2 — PU — CC ..	.24 I	.24	.13	.12
13	SAB — O — CC ..	.24	.22	.14	.15
14	SAB — PU — CC ..	.27	.28 I	.17	.13
15	C — O — O ..	.19 D	.18 D	.16	.14
16	C — O — O ..	.21	.21	.12	.14
LSD @ 5%		0.03			—
Significance:					
Main-plot treatment (T)		**		NS	
Fertilizer level (F)		NS		NS	
Interaction (T X F) ...		NS		NS	

† See Table 1 for key to treatments.
** Significant at 1% level.
NS Not significant at 5% level.

greater than for the check, **but** the differences for the 1966 sampling were not significant at the 5 percent level. However, progressive downward trends of organic matter at both levels of fertilization are indicated for treatments 1, 4, 7, 9. and 15, which do not include sod crops or organic amendments.

At the 0-6-inch depth there is a significant tendency for lower organic matter percentages with ¼ F rate fertilization than with F + N. This is consistent **with** the lower returns of organic matter previously noted. The interaction of main-plot treatment **with** fertilizer level was not significant, although the 0.5 percent difference for fertilizer level under treatments 1,9, 13, and 15 is noteworthy.

Nitrogen

At the 0-6-inch depth, all of the mean nitrogen contents except that for treatment 15 were significantly greater than that for check treatment 1 (table 10). The highest mean values of 0.26 and 0.28 percent for treatments 3 and 14, **respectively,** may be compared **with** 0.17 and 0.18 percent for treatments 1 and 15. The effect of fertilizer treatments was not significant **despite** the great differences in nitrogen **applications** (fertilizer alone or fertilizer and woodchips) as shown in appendix table 1.

Nitrogen uptake by crops was not determined in this experiment. Unpublished results from another experiment on the same soil type .where the crop was corn for grain, indicate that the average annual uptake in the above-ground portion of crop from check plots without N fertilization was 100 pounds of N per acre, which was equal to approximately 2.4 percent of the nitrogen **in** the plow layer. This percentage applied to the nitrogen percentages 0.17 and 0.28 suggests a difference of 50 pounds of N per acre available annually.

Trends of organic matter and nitrogen **with** respect to main-plot treatments were similar. Ratios of nitrogen to organic matter were **approximately** 1:21, 1:19 and 1:17, **respectively,** for the 0-6-inch depths under woodchip treatments, the depths for other treatments, and the 9-12-inch depths for all treatments.

Available Phosphorous

Significant differences between split-plot fertilizer treatments were found **at** both **sampling** depths (table 11). At the **0-6-inch depth,** the interaction of main-plot and subplot treatments was highly significant. At this **depth** for treatments 16, 15, and 1, which represent, respectively, 5, 10, and 15 years under **intensive vegetable cropping with-**

Table 11. *Results of tests for "available" soil phosphorous 1966*

Treatment†		0–6-inch depth		9–12-inch depth	
No.	Coded	F + N	¼ F	F + N	¼ F
		pounds/acre			
1	C — O — O ..	44 I	6	7	1
2	C — PU — O ..	55 I	17 I	8	2
3	C — TD — O ..	42 I	21 I	4	2
4	C — O — CC ..	42 I	7	3	4
5	C — PU — CC ..	42 I	8 I	5	2
6	C — TD — CC ..	53 I	6	2	1
7	I — O — CC ..	24 I	10 I	3	1
8	I — PU — CC ..	21 I	7	1	1
9	SA_1 — O — CC ..	31	4	2	1
10	SA_1 — PU — CC ..	32	8	4	1
11	SA_2 — O — CC ..	21 I	2 D	1	1
12	SA_2 — PU — CC ..	24 I	3	1	1
13	SAB — O — CC ..	30 I	4	2	1
14	SAB — PU — CC ..	23 I	8	1	1
15	C — O — O ..	25 I	5	5	1
16	C — O — O ..	11	3	1	1
LSD @ 5%		9		—	
Significance:					
Main-plot treatment (T)		**		NS	
Fertilizer level (F)		**		**	
Interaction (T X F) ...		**		NS	

† See Table 1 for key to treatment.
** Significant at 1% level.
NS Not significant at 5% level.

Table 12. *Results of tests for "available' soil potassium 1966*

Treatment†		0–6-inch depth		9–12-inch depth	
No.	Coded	F + N	¼ F	F + N	¼ F
		pounds/acre			
1	C — O — O ..	132 I	83 I	87	63
2	C — PU — O ..	190 I	168 I	110	83
3	C — TD — O ..	212 I	222 I	132	82
4	C — O — CC ..	113 I	90 I	60	72
5	C — PU — CC ..	132 I	127 I	67	70
6	C — TD — CC ..	178 I	132 I	75	78
7	I — O — CC ..	138	100	97	60
8	I — PU — CC ..	155	122	70	62
9	SA_1 — O — CC ..	97	80 I	58	65
10	SA_1 — PU — CC ..	168	113 I	92	52
11	SA_2 — O — CC ..	108 I	82	62	60
12	SA_2 — PU — CC ..	132 I	103 I	75	70
13	SAB — O — CC ..	108	105	75	58
14	SAB — PU — CC ..	152	118	72	77
15	C — O — O ..	105 I	93	72	63
16	C — O — O ..	115	92	68	70
LSD @ 5%		48		—	
Significance:					
Main-plot treatment (T)		**		NS	
Fertilizer level (F)		**		*	
Interaction (T X F) ...		NS		NS	

† See Table 1 for key to treatments.
* Significant at 5% level.
** Significant at 1% level.
NS Not significant at 5% level.

out cover crops or woodchips, test values increased from 11 to 25 to 44 at F + N fertilization and only from 3 to 5 to 6 at *Vi* F. The corresponding inputs of P fertilization from appendix table 1 were respectively 238, 475, 713, and 59, 119, 178.

There was no consistent effect of woodchip amendments on soil tests for available phosphorous. However, for those treatments cropped over the entire 15-year period, available phosphorous at the F + N fertilization level ranged from 42 to 55 for the first 6 treatments and 21 to 32 for treatments 7 through 14.

Available Potassium

Significant differences between split-plot, high and low fertilizer treatments were found at both sampling depths, (table 12). The superiority of high-level fertilization compared to low averaged 12.6% at the 0-6-inch depth and 11.3% at the 9-12 inch depth. At neither depth was the interaction of subplot and main-plot treatments significant.

Tests for available potassium at the 0-6-inch depth averaged 50 percent higher for woodchip treatments than for corresponding check treatments. Most of this can be attributed to the additional K added in woodchips (appendix table 1).

Physical Soil Properties

Aggregate Stability

From the beginning of the experiment in 1951 to the fall of 1958, plots were sampled only 7 times for aggregate stability, but starting in the fall of 1958, these determinations were made each fall and spring.

Trends of aggregate stability with time are presented graphically in figure 1 for treatments 1, 15, and 16, representing 5-year intervals of date of initiation; in figure 2 for treatments 1, 3, and 4, representing effects of wood chips and cover crops; and in figure 3 for treatments 1, 9, 11-13, and 12-14, comparing effects of sod and sod plus wood chips. Most plotted values are means of 12 values for main-plot treatments, representing 2 fertilizer levels, 3 plot replicates, and 2 determinations of stability of each sample in the laboratory.

Generally, the stability of samples from F + N subplots were found to be significantly less than samples for ¼ F subplots. Differences, although consistent, were generally small in comparison with effects of main-plot treatments. Interactions of main-plot and subplot data were not sig-

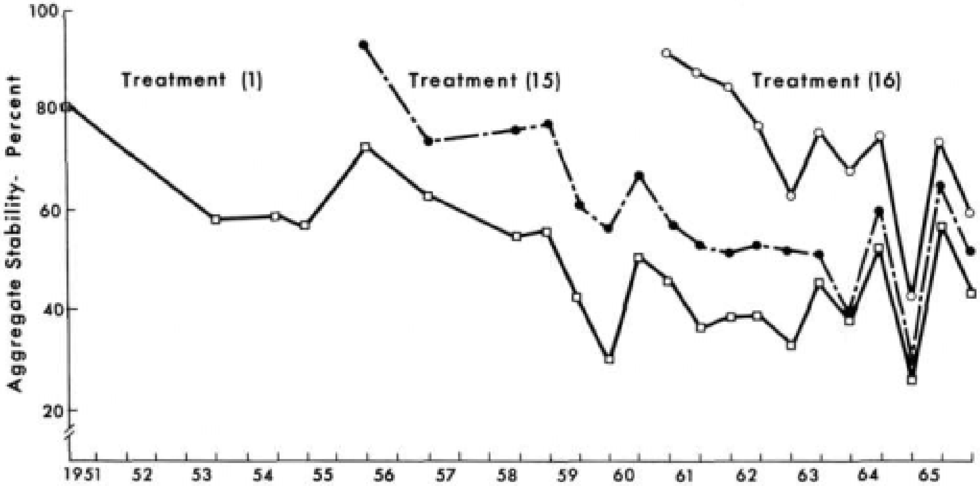

Figure 1. *Soil aggregate stabilities under check management system consisting of continuous vegetable cropping without cover crops or hardwood chips. Treatments 1, 15, and 16 started from sod in 1951, 1956, and 1961, respectively.*

nificant. The reason for the difference associated with mineral fertilization treatments is not known. It seems to be independent of main-plot treatments as well as a reversal of what might be expected from effects on yields and organic matter returns from crops.

Initial aggregate stabilities for the sets of plots started from uncropped and undisturbed old sod at 5-year intervals (figure 1) ranged from approximately 80 to 90 percent. Within each 5-year rotation, the stabilities reached for the rotation following cabbage were low. These low values became progressively lower as cropping continued, but in every case within rotations were followed by a temporary improvement in stability. For peas, this improvement may be attributed to diminished tillage and to the short-term catch crop underseeded with the peas.

Other variations of appreciable magnitude within and between rotations may be attributed to differences in the balance between factors that tend to improve or reduce stability. Among these are organic matter levels and inputs, moisture regimes, rainfall energy, and the extent of freezing and thawing.

Figure 2 shows marked differences in stabilities resulting from either using cover crops or top dressing with woodchips. Superiority of the better soil management practices as compared with check are marked through 3 rotations. Not shown are data for treatment 2, where chips were plowed under immediately rather than left to remain on the soil surface for a year. Although the magnitude of differences in relative effects of treatments 2 and 3 was small, 3 were superior in 18 out of 22 instances.

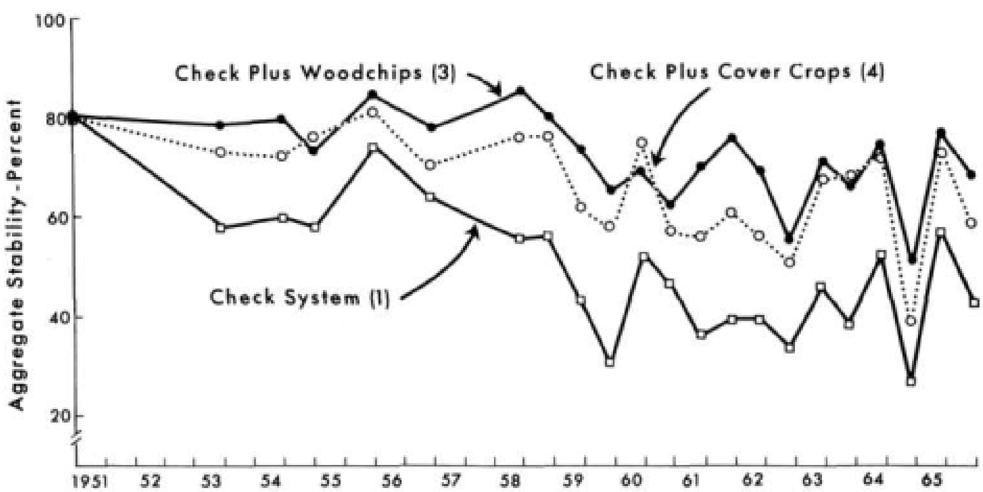

Figure 2. *Soil aggregate stabilities under 3 different management systems over 15-year period. All under continuous vegetable cropping, but treatment 3 included hardwood chips and treatment 4 included cover crops.*

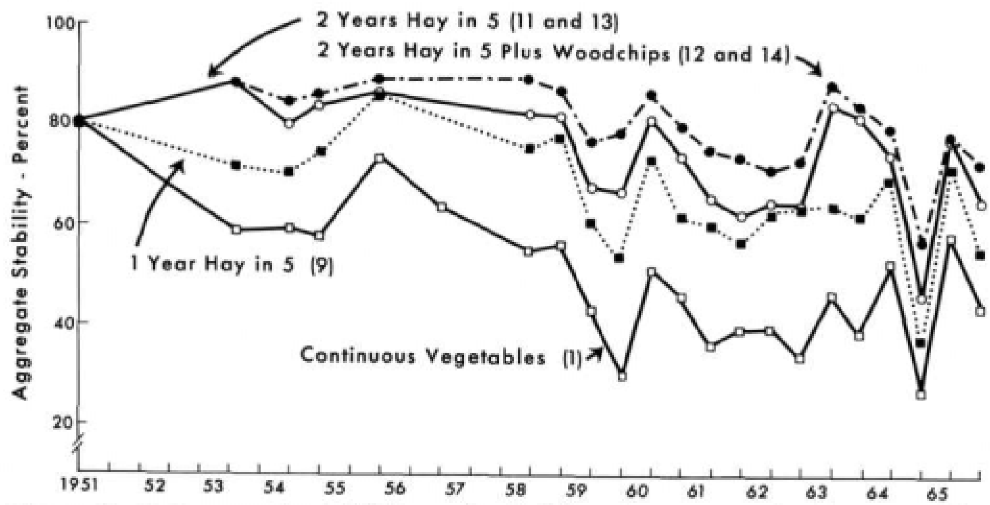

Figure 3. *Soil aggregate stabilities under 4 different management systems over 15-year period. Treatment (1) continuous vegetable cropping; treatment (9) 1 year hay crop in 5; treatments (11 and 13) 2 years hay crop in 5, and treatments (12 and 14) 2 years hay crop in 5, plus hardwood chips.*

Figure 3 compares stabilities under check treatment 1 with those under 9 (cover crops and 1 year sod in 5), under 11 and 13 (cover crops and 2 years sod in 5), and under 12-14 (cover crops and 2 years sod in 5 plus hardwood chips). Only under the systems that included 2 years of sod in 5 were stabilities during the third cycle of the rotation restored temporarily to the initial or starting level of 80 percent. A marked and consistent additional benefit resulted from hardwood chips supplementing 2 years of sod. Treatment 9 compares closely in magnitude of effects with that of treatments 3 and 4 in figure 2. Actually, treatments 3 and 4 were slightly superior to treatment 9 in 15 and 13 comparisons, respectively.

Bulk Densities

Data for selected treatments sampled before plowing in 1956, 1961, and 1966 are presented in table 13. Plots at these times were all in the legume underseeding following peas. Data by year, main-plot treatment, sampling depth, and fertilizer treatment are means of results from 3 to 6 samples.

In 1966 after 15 years of treatment, main-plot treatments and depth differences were significant.

The interaction of main-plot and subplot fertilizer treatments was highly significant. At the high F + N fertilizer level, mean bulk densities, except for treatment 14 (2 years sod in the rotation plus woodchips), were not greatly different from that for the check treatment. At the low *V** F fertility level, however, the mean of 1.40 gms/cc for the check treatment was high.

Undecomposed Organic Matter

The same samples used for bulk density determinations presented in the preceeding section were also used for determination of undecomposed organic material present in the soil. Resulting data are summarized in table 14.

There were marked differences between treatments with and without woodchips. Furthermore, there is a tendency for amounts to increase with successive 5-year rotations where woodchips were used and to decrease or stay the same where they were not.

Table 13. *Bulk density data for selected treatments**

Treatment	Year	2–5-inch depth		9–12-inch depth	
		F + N	¼ F	F + N	¼ F
		grams per cubic centimeter			
Check	1956	1.26	1.30	1.38	1.42
	1961	1.30	1.38	1.37	1.37
	1966	1.22	1.42	1.37	1.39
	Avg.	1.26	1.37	1.37	1.39
Check + woodchips	1956	1.20	1.17	1.27	1.31
	1961	1.16	1.21	1.25	1.23
	1966	1.19	1.20	1.26	1.24
	Avg.	1.18	1.19	1.26	1.26
2-year sod	1956	1.14	1.20	1.31	1.29
	1961	1.21	1.27	1.30	1.29
	1966	1.21	1.33	1.31	1.30
	Avg.	1.19	1.27	1.31	1.29
2-year sod + woodchips	1956	1.14	1.17	1.31	1.28
	1961	1.16	1.20	1.26	1.27
	1966	1.15	1.08	1.23	1.19
	Avg.	1.15	1.15	1.27	1.25

* In 1966 LSD @ 5% level = 0.07

Table 14. *Amounts of undecomposed raw organic matter i(roots, residues, and woodchips) in soil for selected treatments**

Treatment	Year	2–5-inch depth F + N	2–5-inch depth ¼ F	9–12-inch depth F + N	9–12-inch depth ¼ F
		grams per cylinder†			
Check	1956	0.8	0.9	0.3	0.3
	1961	.4	.3	.3	.2
	1966	.5	.4	.2	.2
	Avg.	0.6	0.5	0.3	0.2
Check + woodchips	1956	2.6	2.6	0.7	.2
	1961	2.3	2.0	1.1	1.5
	1966	3.6	4.0	2.0	1.3
	Avg.	2.8	2.9	1.3	1.0
2-year sod	1956	1.3	.8	.4	.3
	1961	1.5	.5	.1	.2
	1966	1.0	.5	.3	.3
	Avg.	1.3	0.6	0.3	0.3
2-year sod +woodchips	1956	2.4	3.5	.5	0.1
	1961	3.5	2.4	2.4	4.3
	1966	4.6	4.0	2.0	2.6
	Avg.	3.5	3.3	1.6	2.3

* In 1966 LSD @ 5% level = 0.8.
† Grams/cylinder approximately equal tons/acre.

The amount of undecomposed organic material present under woodchip treatments nearly equals 1 year's application. This not only indicates that woodchips decompose slowly, but also suggests that the amount added may have been more than enough to achieve the desired effect on soil properties. The effect of rate of application was not studied.

Biological Activity

Results obtained in 1954, 1955, 1956, and 1959 from earthworm counts are summarized in appendix table 5. Hardwood chips increased the number of earthworms by a factor of 3. The 1954 and 1956 data indicate that, regardless of whether woodchips were used, the difference in fertilizer use had essentially no effect on earthworm population.

Losses of dry weight of sticks placed in plots during May 1955, and removed a year later were found to range from 14 to 36 percent, averaging 25 percent. Losses under the F + N and ¼ F treatments averaged 28 and 22 percent, respectively, a highly significant difference. Losses for main-plot treatments with and without woodchips averaged 30 and 19 percent, respectively, which is also a highly significant difference. Mean weight losses from sticks were correlated (r = 0.88**) with mean counts of earthworms in 1955 and 1956. The earthworm counts appear to provide indices of the general biological activity in the soils. Their life cycles may have been important factors in the differential conservation and build-up of soil nitrogen shown by soil tests.

Soil Temperature

Soil temperatures were not routinely measured. Enough data were obtained, however, to show direction and magnitude of effects of certain treatments.

On August 4, 1954, a partly cloudy day, soil temperatures at a depth of 2 inches were manually measured with a dial thermometer. Mean temperatures for plots of the 2 treatments topdressed with wood chips ranged from 75-81°F, averaging 78.2°F. This compares with a range of 82-87°F and a mean of 84.3°F for all other treatments. By September 28, however, the effects of topdressing were no longer observable. Instead, the dominant factor affecting soil temperature was shade from cabbage plants. Mean temperatures for shaded and unshaded areas were 60.4 and 67.6°F respectively.

At a depth of 4 inches on May 27, 1963, when soil temperatures in plots plowed for tomatoes ranged from 53-54°F, the temperature range for plots left in hay, then about 14 inches high, ranged from 50 to 51 °F.

During the winter period when freezing temperatures occur, marked effects of standing crop cover or the lack of it and of the effects of wood chips, particularly when top-dressed, were often noted. Snow caught and held by crop cover definitely inhibited soil freezing. Frozen soil could contribute to increased runoff and breakdown of soil aggregates. Topdressed wood chips also inhibited soil freezing probably due both to higher levels of soil moisture and to greater soil porosity.

Soil Moisture

In late fall 1961, samples for determination of moisture-retention curves were taken from the plow layer of all subplots of treatments 1, 3, 4, and 12. Effects of fertilizer subplot treatments were not significant. Effects of main-plot treatments were highly significant, with differences at tensions of 1/3 and 15 atmospheres as follows:

Main-plot treatment* Number	Main-plot treatment* Coded	Moisture percentages 1/3 atm	Moisture percentages 15 atm	Moisture percentages Difference
1	C — O — O	20.6	8.6	12.0
3	C — TD — O	26.9	11.7	15.2
4	C — O — CC	21.8	10.3	11.5
12	S — A_2 — PU — CC	26.0	11.4	14.6
LSD @	5% level	2.0	1.4	

* See table 1 for key to treatments

Clearly, the effect of wood chips on moisture retention is dominant. Converting mean data for 1/3 and 15 atmosphere moisture percentages of chip and no-chip treatments to a volume basis gives volume percentages of 14 and 31 percent and 13 and 28 percent, respectively. The differences of 17 and 15 percent represent approximations of available moisture capacities by volume.

Results of soil moisture measurements on plots in 1962, 1963, and 1964 made with a surface neutron gauge are presented in appendix table 6. On 8 of the 11 dates, significant effects of main-plot treatments were found. In 1962 and 1963, some of these were associated with crop (hay or vegetables). The mean effects of wood chips and cover crops for continuous vegetables are shown as means in the right-hand column.

Rainfall amounts for the week preceeding measurement, for all dates except July 27, 1962, ranged from 0 to 0.67 inch. The effect of a heavier amount of rainfall, 2.13 inches, is seen in the data for July 27, 1962. Moisture percentages at this time varied from 20 to 28 percent, well within the upper half of the readily available moisture range. All values for 1964 were near or below the lower limit of readily available moisture. Cabbage yields for 1964 thus show the importance of subsoil moisture in a dry year.

Significant effects of fertility levels, F + N and ¼ F, were found in the data for September 6, 1962, August 9, 1963, and August 20, September 16, and October 14, 1964. Values for the F + N level averaged about 1 percent higher than for the ¼ F level. This may be associated with a greater amount of crop canopy that provided more shade for the soil.

Relative Erosion Losses

Wischmeier and Smith (1965) presented and discussed rainfall (R), soil erodibility (K), slope length (L), slope gradient (S), cropping management (G), and erosion-control practice (P) as dominant factors in an equation for predicting mean annual soil loss from a given area.

Part of their specifications for the soil-erodibility factor K states that it represents "land that has been tilled and kept free of vegetation for a period of at least two years or until prior crop residues have decomposed." This implies, of course, that residual effects of previous cropping and management might be expected to be present for at least 2 years under fallowing and without further differential treatment. Residual effects should thus be reflected in factor C.

Plots of selected treatments were plowed and fallowed early in both 1966 and 1967. Rain simulator plots 12 feet wide and 35 feet long were laid out on them. A boom-type rain simulator (Swanson, 1965) was used for determination of relative erodibility as a short-term residual of past management. Simulated rain was applied at an intensity of 2 '/a inches per hour in 3 separate 30-minute "storms" closely following each other the same day, as described under *Materials and Methods.*

Erosion and runoff data determined in 1967 as residual effects of 6 selected treatments are presented in table 15. These data are arrayed left to right in order of increasing aggregate stability determined on 0-6-inch samples taken™ just before the rain simulator tests in 1967. Differences in erodibility of treatments and in the magnitude of the negative correlation with aggregate stabilities were most marked in the data for the first storm. Mean total erosion for these 6 treatments in 1967 was only 6 percent more than in 1966, but significance of treatment effects was greater in 1967, probably because of transient effects of the catch crop plowed under in 1966. Procedures and techniques may have been better standardized in 1967 than in 1966, which was the first year of using the rain simulator.

These data show residual benefits of hardwood chips and of sod-based rotations. Erosion and runoff of treatments 1, 15, and 13 which did not receive wood chips should be compared with treatments 3 and 14, which did. Obviously, however, they cannot show aggregate and cover effects of all years of a rotation. For example, erosion under treatments 13 and 14 while in sod would probably be neglible. Furthermore, had tests of these particular plowed treatments been made in 1964, the first year after 2 years of sod, benefits would probably have been greater than in 1966 or 1967. Similarly, the measured erodibility of treatment 3, topdressed with wood chips immediately after planting vegetable crops, in these erosion tests did not include the surface-protection effects of the wood chips.j Finally, favorable effects on erosion and runoff would probably have resulted from the better crop canopies associated with the higher yielding treatments.

Table 15. *Erosion and runoff losses 1967*

	Treatment number*					
	1	15	13	3	14	17
Erosion			tons/acre			
Storm 1	2.1	2.4	1.8	0.9	0.9	0.6
Storm 2	6.2	3.9	3.7	2.8	3.7	2.9
Storm 3	6.2	4.2	3.8	3.5	4.1	4.0
Total	14.5	10.5	9.3	7.2	8.7	7.5
Surface runoff			inches			
Storm 1	0.4	0.6	0.6	0.3	0.3	0.2
Storm 2	.9	1.1	1.1	.9	0.9	0.7
Storm 3	1.1	1.2	1.1	1.0	1.0	0.9
Total	2.4	2.9	2.8	2.2	2.2	1.8
Aggregate stability			percent			
Before runs ..	24	24	33	46	57	71

* All treatments except 17 are fully described in table 1. Number 17 was freshly broken from sod and would have been a check treatment similar to 15 and 16 had the experiment been continued.

Discussion

The effects of split-plot fertilizer treatments F and ¼ F on yields were marked and highly significant, as expected. The recommended level F compared with ¼ F increased cabbage yields by 28 percent and yields of other vegetable crops by amounts ranging from 10 to 15 percent. The average benefit to cost ratio for F compared with ¼ F over a rotation would approximate 3 to 1.

Vittum and associates (1956, 1958, and 1959) report that at Geneva, New York, doubling the normal rates of fertilization (2 F compared with F) for cabbage, tomatoes, and sweet corn on a Lima silt loam (moderately well-drained equivalent of Honeoye) had only minor effects on yields of marketable product.

At Marcellus, extra nitrogen over base fertilization levels increased mean yields of sweet corn, beans, and cabbage by only about 5 percent. The effect of extra N on peas was to significantly decrease yields by 4 percent while the effect on tomato yields was not significant.

In the Marcellus study, beneficial effects of the F level of fertilization for vegetables were noted on yields of hay in rotation, the catch and cover crops, and vine weights of tomatoes. Presumably, similar effects could have been found for other crop residues.

| Maximum effects of main-plot treatments on 3-year mean vegetable yields (table 4) ranged from 25 to 27 percent for sweet corn, beans, and peas and to 36 to 40 percent for tomatoes and cabbage. Despite the use of hardwood chips as an organic amendment under some treatments, the interactions of main-plot and subplot treatments were mostly not significant.

The effect on soil tests of F + N fertilizer treatments compared with ¼ F ranged from highly significant for pH, available phosphorous, and potassium, and significant for organic matter to nonsignificant for total nitrogen. The effect of main-plot treatments was highly significant in every instance. The interactions of main-plot and subplot treatments, except for available phosphorous, were all nonsignificant.

The finding that, contrary to expectation, most of the interactions between subplot and main-plot data were not significant is considered an outstanding result of this experiment. This applies to both crop yields and soil tests.

When woody materials are used as direct soil amendments, recommended amounts of additional nitrogen range from 10 to 20 pounds per ton dry basis for woodchips to 24 to 30 for sawdust (Allison and Anderson, 1951; Mc-Intyre, 1952; and Lunt, 1955). For the hardwood chip treatments in this experiment, the minimum nitrogen rec-pommended would be 70 pounds per acre. This was not supplied for any crop by 14 F treatments without supplementary N and not supplied for any crop except tomatoes and cabbage by the full F level without supplementary N.

The high starting levels of soil organic matter and structure in this experiment may account at least in part for the generally favorable effects found for woodchips, even at low levels of additional nitrogen. The problem was one of maintenance and possible improvement rather than one of rebuilding the soil structure.

The high uptake of N (average 100 pounds per acre) by field corn on Honeoye soil with no mineral N fertilization has already been mentioned. Bouldin and Lathwell (1968) have stressed the importance of soil organic nitrogen on plant growth. Limited use of hardwood chips on two other New York soils poor in structure and with organic matter already nearly down to 2 percent indicated that, while recovery of good structure and productivity might eventually be possible on these soils, it is not a short-term task under continued intensive cropping.[2]

Another reason for the generally favorable effect of woodchips in this study may be that they were hardwood rather than soft-wood chips. Bear and Prince (1951) compared hardwood (oak) and softwood (pine) shavings as amendments to 2 soils for snap bean and carrot production. Pine shavings were considerably less effective than oak shavings for carrots on a loam soil.

Allison (1965) reported that hardwoods decomposed much more readily than most of the softwoods tested. He advanced the idea that celluose may be readily attacked when in a pure state, but if present in intimate relation to lignin or resinous materials, it may be decomposed slowly and only as these other wood constituents are broken down. The differences in decomposition rates of hardwood and softwood species were not specifically a function of nitrogen content nor of added nitrogen. Allison also found that garden peas grown in soil-sawdust mixtures with adequate nutrients present showed no significant toxic effects from woods and barks of 22 of the 28 species tested. Five of the 6 species showing some toxicity were softwoods — specific varieties of pines or cedars.

Hardwood species are readily available in New York with nearly half (47%) of the land area of the state covered with forest and with hardwoods dominant on about 84 percent of the 12 million acres of commercial forest land (Armstrong and Bjorkbom, 1956).

Mclntyre (1952) estimated that woodchips could be produced for about $5 per ton. He also pointed out that the use of woodchips for vegetable production helps to approach the ideal of woodland management — the complete and sustained use of all tree crops grown. There would also be an immediate profit incentive for better pruning and culling by wood-lot owners. While results

[2] Unpublished results of studies by the author and M. T. Vittum on an eroded Collamer silt loam at Geneva, New York and W. C. Jacob on a Bridgehampton loam at Riverhead, New York.

from hardwood chips used in the Marcellus study were impressive, it may be possible to improve the yield benefit to cost ratio by using lower rates or less frequent application.

On Honeoye soil at Marcellus, hardwood chips accounted for much of the yield increases over check and much of the favorable effects on soil properties. An outstanding treatment was number 3, with continuous cropping to vegetables and hardwood chips applied after planting. These chips remained at the soil surface to be plowed under the following year. Soil nitrogen under this treatment at the 0-6-inch depth was 0.26 percent in 1966 compared with 0.23 percent under treatment 2, which had the wood chips plowed under, and 0.17 percent under the check treatment without wood chips. From the standpoint of soil N buildup on fallow plots, Albrecht (1936), using red clover as a soil amendment over a 15-year period in Missouri, found topdressing one year and plowing under the next slightly superior to plowing under immediately. The Missouri plots had board curbings enclosing them to to prevent differential erosion losses.

Treatment 14, which had 2 years of sod, plus wood chips, plus cover crops for vegetables, was another outstanding treatment with respect to the effect of hardwood chips on total nitrogen present in the soil at the end of the experiment. The mean value of 0.28 percent was higher than the 0.23 percent of similar treatment 13 without chips.

In the Marcellus study, the simple linear correlation of 16 mean main-plot yields of cabbage in 1964 with 1966 soil nitrogen data for the 0-6-inch depth was highly significant (r = 0.75), as was the corresponding correlation with soil organic matter (r = 0.62). Some idea of the importance of physical properties of soil on these yields as influenced by main-plot treatments was provided by correlations of these same cabbage yields with mean soil moisture contents and mean aggregate stabilities for 1964. The respective simple correlation coefficients were 0.66** and 0.55*. Bulk densities were markedly affected by main-plot treatments, but because of incomplete data could not be used for correlations.

The beneficial effects of winter cover crop and of sod crops in rotation on vegetable yields in this experiment were not impressive when compared with the effect of hardwood chips. While part of the poorer yield performance may be associated with greater competition for nutrients and moisture from cover crops than from wood-chips, data on this point are not conclusive in this experiment. Vittum and associates (1958) cite an interesting instance where germination and growth of ryegrass in tomatoes as influenced by supplemental irrigation markedly affected yields. Similar effects could well be a function of year-to-year differences in rainfall.

Organic matter from winter cover and sod crops and from hardwood chips also differed in amount in this experiment and could be expected to differ in lasting qualities. In terms of relative effects on erosion and runoff and on nutrient losses above and below ground contributing tea pollution, growing crops should rate higher than a car-ried-in amendment.

Summary and Conclusions

Over the years 1951-1966, several systems of soil management for vegetable production were evaluated by field-plot study on Honeoye silt loam at Marcellus, New York. Soil physical condition and organic matter were at relatively high levels at the start of this experiment.

Rainfall from May through September during the years of this experiment ranged from 10.4 inches in 1964 to 20.6 inches in 1958, compared with the long-term mean of 15.7. Crop yields were generally satisfactory.

Vegetable crops were sweet corn, dry beans, tomatoes, cabbage, and peas. Management systems ranged from continuous vegetable cropping to sod-based rotations. Included were treatments with and without winter cover crops and with and without hardwood chips as a carried-in soil amendment. Effects of both normal and low fertilizer rates and of supplemental nitrogen and the interactions of both with main-plot treatments were studied by a split-plot design.

1. Main-plot management systems involving cropping sequences, cover crops, and organic amendments, had greater effects on crop yields and on most soil chemical and physical properties than did subplot fertilizer treatments.

2. Except for sweet corn yields, interactions of main-plot and subplot treatments were generally not significant. This is regarded as an important but unexpected finding.

3. The main-plot treatments that included hardwood chips as a soil amendment were particularly beneficial in terms of effects on crop yields, on several chemical and physical soil properties, and on indices of soil biological population and activity.

4. Under continuous cropping to vegetables, topdressing with hardwood chips after planting (the chips to be plowed under the following year) was an outstanding treatment with respect to effects on yields and maintenance or buildup of soil nitrogen and structure.

5. The crop showing the greatest percentage of yield benefit from main-plot treatments was cabbage, for which the difference between highest and lowest 3-year mean yield was 6.1 tons per acre. Next was tomatoes, with a difference of 5.7 tons per acre, and with effects significant for two years out of three.

6. Although amounts of nitrogen added as mineral fertilizer differed by 5- to 10-fold, with significant effects on vegetable yields, on yields of cover and catch crops, and on

yields of crop residues and sod crops in rotations, effects on soil tests for organic matter and nitrogen at the end of "the study were slight compared with effects of main-plot treatments.

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Appendix

Appendix table 1. *Total N, P, and K applied as commercial fertilizer over 15-year period 1951–1965 for highest and lowest split-plot treatments**

Number and system		N		P		K	
No.	Cropping system†	F + N	¼ F	F + N	¼ F	F + N	¼ F
				lbs/acre			
1–6	Vegetables, 15 yrs.	2,310	202	713	178	672	168
7–8	Intermediate	1,770	510	554	238	523	224
9–10	Sod-based, 1 yr.	1,920	180	739	264	797	349
11–14	Sod-based, 2 yrs.	1,380	120	581	264	697	398
15	Vegetables, 10 yrs.	1,540	135	475	119	448	112
16	Vegetables, 5 yrs.	770	68	238	59	224	56

* On estimated basis of 4–2–4 pounds of N, P_2O_5 and K_2O per ton of dry woodchips (Allison and Anderson, 1951) additional amounts of N, P, and K respectively applied to all subplots of hardwood-chip treatments 2, 3, 5, 6, 8, 10, 12, and 14 were 420, 92, and 340 pounds per acre over the 15-year period.

† See table 1 for complete descriptions of cropping systems.

Appendix table 2. *Growing season — monthly precipitation departures from 31-year monthly means at Marcellus*

Year	May	June	July	August	Sept.	October
			inches			
1951	–1.0	0.8	3.0	–0.7	0.1	–1.4
1952	1.2	–1.9	0.6	–1.4	–0.9	–0.4
1953	1.6	–1.6	1.7	0.2	–0.6	–1.7
1954	–1.2	0.8	–3.0	0.4	–0.8	–1.1
1955	–0.4	–1.2	–1.7	1.0	–0.8	5.9
1956	0.9	–1.9	0.5	3.8	0.8	–1.4
1957	0.7	0.7	1.5	–1.0	–0.4	–1.7
1958	–1.2	2.1	1.0	0.1	2.8	0.6
1959	–1.7	0.4	0.2	–1.1	–1.8	4.4
1960	1.5	–0.4	–1.9	1.1	–0.8	–0.6
1961	–0.1	1.2	0.7	–1.6	–2.0	0.8
1962	–1.9	–1.6	–0.1	0.1	–0.5	–0.4
1963	–0.2	–1.6	–0.3	1.5	–1.4	–2.9
1964	–0.3	–2.1	–0.9	–0.2	–1.8	–1.6
1965	–1.9	–1.5	–1.2	–1.1	1.6	0.2
31-year mean	3.1	3.2	3.4	3.1	2.9	3.1

Appendix table 3. *Four-week periods ending May 2 through October 31 with precipitation ≦ 1.40 inches**

1951	None (1.54) +
1952	5/2, 5/9 (0.52), 6/27, 7/4, 9/5, 9/12
1953	6/27 (1.18), 9/12, 10/24
1954	7/25 and 8/1 (0.32), 8/8, 8/15, 8/22, 10/31
1955	6/6 (1.16)
1956	6/20, 7/4 (1.08), 10/24
1957	5/9 (0.73), 10/3, 10/10
1958	None (1.99)
1959	5/9, 5/30, 9/12, 9/19, 9/26 (0.58)
1960	7/18 (0.87), 10/10, 10/17
1961	9/5, 9/12, 9/19, 9/26 (0.88)
1962	5/23, 5/30 (0.50), 6/6, 7/4, 7/11, 7/18, 9/12, 9/19, 9/26
1963	7/18, 9/26, 10/3, 10/10, 10/17, 10/24, 10/31 (0.06)
1964	6/27, 7/4, 7/11, 7/18, 9/19, 9/26 (0.46), 10/3, 10/10, 10/17, 10/31
1965	5/30, 6/13, 8/1, 8/8 (0.72), 8/15

* Mean daily precipitation over 4-week period ≤ 0.05 inches/day.

\+ Values in ( ) are minimum 4-week precipitation.

Appendix table 4. *Log of planting and harvesting dates*

Crop and year	Planted	Harvested**
Sweet corn		
1951 ...	5/18 (replanted 5/31)	8/2 — 8/17
1956 ...	5/15 (replanted 6/15)	9/4 — 9/10
1961 ...	5/18	8/15 — 8/24
Beans		
1952 ...	6/10	9/26
1957 ...	6/5	9/24
1962 ...	6/4	9/26
Tomatoes*		
1953 ...	5/28	8/12 — 10/1
1958 ...	6/4	8/28 — 10/2
1963 ...	6/5	8/23 — 10/15
Cabbage*		
1954 ...	7/1	10/12
1959 ...	7/1	10/29
1964 ...	6/25	11/9
Peas		
1955 ...	4/20	6/29
1960 ...	5/2	7/20
1965 ...	5/5	7/9
Hay		
1951 ...	8/25	1952 — 6/24, 7/30 1953 — 6/9 , 8/3
1956 ...	10/1 (additional 4/4/57)	1957 — 7/29, 9/9 1958 — 6/24, 8/11, and 10/8
1961 ...	9/1	1962 — 6/20, 9/11 1963 — 6/25, 8/12

* Individual plants replaced as needed.

** Range of harvest or picking dates for sweet corn and tomatoes. Dates of hay harvests — 2 cuttings per year, (3 in 1958).

Appendix table 5. *Earthworm counts per 40-foot furrow**

Main-plot treatment number	1954		1955	[illegible]		1959	Mean
	High fertilization	Low fertilization		High fertilization	Low fertilization		
1	5.9	4.9	3.2	2.0	1.4	4.0	3.6
2	25.6	17.5	10.1	6.8	5.7	28.8	15.8
3	15.9	16.6	9.4	5.9	4.9	22.6	12.6
4	5.9	6.3	3.8	2.3	2.2	6.6	4.5
5	12.7	15.0	8.8	8.2	7.1	29.0	13.5
6	12.0	16.0	8.4	4.7	5.6	25.2	12.0
7	2.4	2.2	3.7	2.6	1.8	5.2	3.0
8	5.0	6.7	9.6	6.3	5.7	14.6	8.0
9	6.2	7.5	3.3	2.2	2.6	10.2	5.3
10	16.7	16.3	9.7	8.5	6.8	16.5	12.4
11	5.6	4.8	3.2	2.8	3.0	5.2	4.1
12	9.7	10.3	9.7	7.0	6.4	21.1	10.7
13	3.6	3.1	2.9	2.3	2.3	4.4	3.1
14	7.5	6.8	7.1	5.6	6.0	14.0	7.8
Means							
Chips	13.1	13.1	9.1	6.6	6.0	21.5	11.6
No chips	4.9	4.8	3.4	2.4	2.2	5.9	3.9
Ratio	2.7	2.7	2.7	2.8	2.7	3.6	3.0

* Earthworms readily visible to person walking behind plow.

Appendix table 6. *Soil moisture data 1962–1964**

Main-plot treatment number	1962			1963			1964					
	6/21	7/27	9/6	6/3	8/9	10/4	7/16	8/6	8/20	9/16	10/14	
					moisture — percent by volume							
1	16	24	17	19	17	17	13	10	13	10	14	15
2	19	26	20	19	21	21	15	12	15	12	15	18
3	18	24	20	22	21	24	17	13	17	12	17	19
4	17	26	18	20	21	21	15	11	14	11	15	17
5	17	28	20	19	22	20	15	12	15	11	16	18
6	19	25	20	20	22	19	17	13	15	12	15	18
7	17	25	23	17	18	19	15	11	14	10	14	—
8	18	26	25	19	19	20	16	12	15	12	14	—
9	11	20	16	21	21	21	15	12	14	11	15	—
10	12	20	17	21	20	18	15	12	16	11	16	—
11	11	21	15	19	17	19	16	12	14	11	15	—
12	12	22	15	20	16	16	16	13	15	11	15	—
13	10	20	15	17	16	16	16	12	15	11	16	—
14	12	23	16	20	19	20	16	12	17	11	15	—
15	15	21	16	20	19	19	15	10	14	10	14	16
16	16	24	17	20	20	20	16	11	13	10	14	16
Treatment 5% LSD	3	3	2	NS	2	1	1	2	NS	1	NS	

* Measurements by N/C model P 21 surface neutron gauge and 2800 scaler. For crops present each year, see table 1. Respective ranges of available moisture (between 1/3 and 15 atm.) for chip and no-chip treatments were 14 to 31 percent and 13 to 28 percent (see text).

Contents