Rotations, Organic Matter, and Vegetables

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That continuous and clean cultivation is a folly, exhausting soil vitality, is an easy conclusion for a nation of men who have seen gullies in hillside corn fields and denuded woodlands, muddy rivers, and dusty skies. This vitality of the soil is difficult to define and is usually equated with the organic matter which disappears during cultivation. To this lost organic matter is attributed potentiality for increased yields and for improved nutrition of man and his animals.

The growing of two crops of vegetables each year, year in and year out, is a common practice on the limited acreage of Connecticut soils suitable for truck gardening; this clean cultivation of two crops each year seems extremely exhaustive for the soil. Whether this is in fact a pernicious practice is tested in the experiments reported here: for 8 years early spinach and late cabbage were grown continuously on the commercially-fertilized Cheshire fine sandy loam of the Lockwood Farm in Mt. Carmel and compared to the vegetables grown in five rotations where green manure was plowed into the soil.

Review of Literature

The function of rotation and green manure is conceived to be first an increase in the organic matter in the soil. This change is, in turn, thought to increase the available nutrients and to improve soil structure and, hence, moisture storage. Finally, whether these alterations are "improvements" is judged in terms of increased yield or improved quality of the plants grown upon the soil. Many years of experiments throughout the world permit us to predict how these changes will proceed in our experiments.

An increase in organic matter in the soil will surely follow the incorporation of shoots and roots of green manure (30). The quality as well as the quantity of the increased matter is apparently important (3).

The durability and level of organic matter attained is, we might as well recognize, not wholly within our control. Under a given management system, the organic matter content tends to remain at about the same level. An illuminating example occurred in Puerto Rico: as much as a thousand tons of filter press cake from sugar-cane was incorporated into a sandy soil in one year. Although this amendment was equivalent to 30 to 40 per cent of organic matter in the plow layer, practically all organic matter decomposed in 2 or 3 years; and no residual value could be detected (11). In Merrimac soil of the Connecticut Valley the annual burial of a cover crop did not prevent the decline of organic matter in a tobacco field converted to vegetable growing (15), and in the Merrimac soil of Tolland County, rotation and the burial of a green manure crop also failed to halt the decline in organic matter accompanying vegetable growing (10). Thus we can expect a temporary increase in organic matter content following rotation or the burial of a green manure and then a return to the equilibrium content for truck farming.

Whether the shoots of a green manure crop are buried or removed, leaving only the roots to decay, may be of little consequence. If the soil has a "constancy factor" (11) for organic matter, the addition of a great deal of this matter may be no more effective than the addition of some. Since roots comprise about half the body of the plant, they may be the "some" that is adequate.

In the past, green manures were used for their fertilizer value. Not until recent times were they considered a means of increasing organic matter. That green manures increase the nitrate in the soil, even without legumes in the manure, is clear (30). With the advent of cheap nitrogenous fertilizers, however, the use of green manures as a source of nitrogen may not be economically advisable. Hence, the nutritional advantages of green manure must be sought in less obvious places.

These other places are not only less obvious, they are obscure. That nutritional advantages do exist, however, is suggested by the observation that the turnover, and not the level, of organic matter is important (3). The existence of nutritional advantages is also indicated by the observation of benefits from burned green manure (6). Further supporting this theory are the differences in benefits from different plants preceding a crop as shown in a series of publications from Rhode Island, beginning with Bulletin 175 in 1918. Thus, we may expect some inexplicable nutritional benefits from our green manures.

The structure of the soil, measured by its aggregation, is improved by rotation to sod or cover crop rather than by continuous vegetable growing (20).

If the increased aggregation increases the number of pores that retain water after rain but that do not retain water from the roots, the moisture-storage capacity of the soil will be improved. Or, if the buried stems and leaves of the green manure increase the average size of pores sufficiently to impede the downward capillary movement of rain, the storage capacity of the soil above will be increased. Investigators (17, 30) have observed increased moisture in the soil with cover crops or added organic matter, suggesting that moisture storage is in fact improved. Repeated dressings with barnyard manure increased the available water in Broadbalk soil (21, p. 379). The final criterion of desirability of rotations and green manure is, however, the change they work in the plant.

Increased yields immediately following a rotation or the burial of a cover crop are generally observed. Unfortunately the benefit may be fleeting. For example, increased yields of vegetables were observed no more than one season after the addition of green manure to an Alabama field (30). Thus, increased yield for a year or two seems a sure consequence of green manure, but the cause of the increase is less sure.

In the beginning of our review we mentioned increased organic matter, increased available nutrients, and improved structure of the soil as possible causes of these increased yields. The first hypothetical cause is increased organic matter. But Figures 33 and 34 of Janes *et al.* (10) show a remarkable lack of correlation between the yields of lettuce or onions and the organic matter content of the soil on which they were grown.

The second hypothetical cause is increased available nutrients, excluding nitrogen which can now be purchased economically. This may be valid, because burned green manure was as effective as that buried intact (6). Further, after commercial nitrogen had been added until little benefit could be gained from further addition, the yield of vegetables could still be increased by the burial of green manure (30).

Increased aggregation and water storage were the final reasons proposed for the efficacy of green manure and rotation. But the correlation between aggregation and yield of sweet corn, garden peas, or potatoes was negligible (20). And DeBoodt *et al.* (5) found that their best method of measuring stable aggregates was correlated with yields in only 2 or 3 years out of about every 4 or 5 and explained, "Whether or not there will be a correlation seems to depend on the weather. A good structure for a drouthy year may be a poor structure for a wet year and vice versa." All this made us confident that in our experiments we would observe temporary increases in yield but the cause of these increases would remain in doubt.

In a rotation, the quality of the vegetable crop, as measured by the proportion marketable, will increase as well as the yield (30). The nutritional value of the plant may, however, interest the consumer as much as the marketability of the plant. The improvement of nutrition is often the goal of organic gardeners.

Members of the Technical Committee of the Southern Regional Soils Weather Project (24) collected turnip greens grown on the soils of four states, from North Carolina to Oklahoma, and determined their vitamin and mineral content. The organic matter contents of the topsoils varied from 0.58 to 2.16 per cent. Two of the fields, one in Texas and one in Oklahoma, provide a nice comparison: although the weather was not markedly different, the organic matter of the topsoil was markedly different at the two sites. Nevertheless, the vitamin and mineral composition of the greens grown at the two sites was not significantly different except in calcium content; calcium was more plentiful in the greens grown on the soil with lower organic matter (Table 1).

Table 1. The composition of turnip greens harvested in the spring (24)

State	Organic matter in soil, %	Ascorbic acid, mg./100 g.	Thiamine µg./100 g.	Riboflavin µg./100 g.	Calcium me./100 g.	Iron mg./100 g.
			Soil			
Oklahoma	2.16	1,027	1,336	2,158	124	27.4
Texas	.58	1,114	1,411	2,664	156	21.9
			Soil or Sand Culture			
Puerto Rico	2.76	1,042	1,707	2,597	175	37
Puerto Rico	Sand	1,071	1,410	2,332	202	24

Another important comparison can be made between the greens grown on the Puerto Rican soil containing a high 2.76 per cent organic matter in the topsoil and greens grown in sand culture nearby. Of the five vitamins and minerals tabulated, thiamine is significantly higher in the soil-grown, and calcium in the sand-grown, greens; the other components do not differ significantly (Table 1). These findings of the Southern group do not lead us to expect large changes in the composition of vegetables grown on soils whose organic matter has been changed by rotation and the burial of green manure.

Concerning one of the vegetables we grew, Tressler *et al.* (27) found that the vitamin C content of several spring or autumn varieties of spinach was about one-third lower where they were grown on organic-matter-rich muck instead of upland soil. This observation fails to indicate that quality, in this case vitamin content, will be improved by increased organic matter in the soil.

This survey of the experience of others tells us that rotation of crops will increase both the organic matter in commercially fertilized soil and the yield of vegetables from it, but that the effect will be modest and transitory. It tells us that the constitution of the produce will not be greatly altered. We shall now turn to our own 8 years of experiments, asking whether any of five rotations where green manure was plowed into the soil were beneficial compared to the continuous growing of early spinach and late cabbage.

Materials and Methods

In the spring of 1953, five blocks of six plots, 12 by 24 ft., were laid out. The field at the Lockwood Farm in Mt. Carmel is Cheshire fine sandy loam, has a 6 per cent slope to the north, and had grown row crops, corn, and carrots for many years. The rotations included 1, 2, and 3 years of spinach and cabbage with 1 or 2 years of green manures. The green manures included alfalfa with timothy, red clover with timothy, alfalfa with domestic rye grass, an annual alfalfa with red top, and annual sweet clover with domestic rye grass (Table 2). The 1-year rotation was continuous vegetables and winter cover of oats.

Table 2. The rotations

Code[a]	1953	1954	1955	1956	1957	1958	1959	1960
V	V	V	V	V	V	V	V	V
AV	A	V	A	V	A	V	A	V
SV	S	V	S	V	S	V	S	V
PPVV	P	P	V	V	P	P	V	V
RRVV	R	R	V	V	R	R	V	V
P'P'VVV	P'	P'	V	V	V	P'	P'	V

[a] V, spinach followed by cabbage except lettuce followed by cabbage in 1953, oat cover in fall; A, annual alfalfa and red top; S, annual sweet clover and domestic rye grass; P, perennial alfalfa and timothy; R, red clover and timothy; P', perennial alfalfa and domestic rye grass.

The accumulation of dry matter per acre in the shoots of the forage plants in the 2-year rotations AV and SV was about 31 cwt. in 1955, 14 in 1957, and 46 in 1959; the corresponding nitrogen accumulations were about 70, 36, and 84 lb. The accumulation of dry matter in the shoots of the forage plants in the 4-year rotations PPVV and RRVV was about 46 cwt. in 1954 and 58 in 1958; the corresponding nitrogen accumulations were 105 and 124 lb. The shoots of the forage plants in the 5-year rotation P'P'VVV accumulated 30 cwt. dry matter and 74 lb. nitrogen in 1954 and 52 cwt. and 121 lb. in 1959.

Each plot was divided into east and west halves. When the plots were growing grass and legume, the west halves were mowed and the hay removed twice a year. The hay was mowed once, but not removed, from the east halves. The grass and legume were plowed into the soil in the spring, shortly before spinach was planted (Table 3), thereby providing maximum erosion control.

The spinach received 1,600 pounds per acre of a 5-10-10 fertilizer and the second crop, cabbage, received 800 pounds of a 10-10-10 fertilizer. Spinach

Table 3. Chronology

Year	Plow	Plant spinach	C,N sample	Aggregate sample	Harvest spinach	Set cabbage	Moisture sample	Harvest cabbage
1953	4/9	4/20[a]	3/?	....	6/8[a]	6/15	....	10/20
1954	3/24	4/12	....	....	6/9	6/15	....	9/20
1955	4/16	4/18	....	5/13	6/8	6/15	....	9/15
1956	4/17	4/20	....	5/23	6/8	6/20	....	9/19
1957	4/11	4/17	5/29	5/28	6/7	6/21	8/12	9/26
1958	4/11	4/25	5/27	5/27	6/18	6/27	8/17	9/26
1959	4/21	4/23	5/27	5/25	6/10	6/23	7/17	9/16
1960	4/12	4/19	5/26	5/24	6/9	6/24	7/29	9/22

[a] lettuce.

responds to nitrate up to 150 pounds per acre (23); increasing nitrogen from 60 to 90 pounds per acre increases cabbage yields less than one-tenth (29). The green manure crops annually received 800 pounds per acre of a 5-10-10 fertilizer. The soil reaction was maintained at about 6.5 pH by liming.

Samples of the plowed soil were taken at the times given in Table 3 and analyzed for total nitrogen (28) and organic carbon (22). Undisturbed soil cores were taken with a modified Lutz core sampler (25) for bulk density, penetrability, and non-capillary porosity (19). Real specific gravity, aggregation (31), wilting coefficient (4), and the moisture retained by the soil after a rain were also determined.

During the year of vegetables a crop of Savoy spinach was followed by late Penn State Ballhead cabbage, except in 1953 when the early crop was lettuce. The vegetables were harvested at the times given in Table 3, weighed samples were dried overnight at 80° C., and the foliage analyzed for the following constituents: Moisture; protein, ammonia, and total nitrogen (28); nitrate nitrogen (2); oxalic acid (18); thiamine (8); riboflavin (1); and iron and calcium (spectrograph).

The data for each characteristic and each year were subjected to analysis of variance. The significance of the difference between continuous rotation and all rotations appearing that year was determined. We also made any meaningful comparisons among the data for rotated plots and determined their significance. In the tables, the significant differences are indicated by stars ($P = .05$) or footnotes to the mean yields that differed from the continuous vegetables or less beneficial rotations.

THE SOIL

The carbon and nitrogen content of the soil decreased during the 8 years of continuous vegetable growing (Tables 4 and 5). After transforming the data into logarithms to equalize variability, one finds that the carbon in the soil decreased a significant 9 per cent (of the 1953 level) between 1953 and 1960. This observed annual decrease of slightly more than 1 per cent of the carbon is nicely within the expected range of 1 to 2 per cent (3). After the logarithmic transformation, one also sees that the nitrogen in the soil decreased a highly significant 20 per cent (of the 1953 level) during the 8 seasons.

Table 4. Organic matter expressed as percentage carbon in the plow layer

Code	1953	1957	1958	1959	1960
V	1.34	1.45	1.35	1.39	1.22
AV	1.40	....	1.52*	....	1.43*
SV	1.47	....	1.55*	....	1.41*
PPVV	1.62	....	....	1.54*	1.44*
RRVV	1.53	....	....	1.57*	1.46*
P'P'VVV	1.37	1.46	....	....	1.36*

* Significantly different from mean for V.

Table 5. Nitrogen content of plow layer, per cent

Code	1953	1957	1958	1959	1960
V	.133	.177	.131	.113	.106
AV	.139	....	.148*	....	.115*
SV	.137	....	.147*	....	.112*
PPVV	.155	....	....	.123*	.124*[a]
RRVV	.142	....	....	.136*	.122*[a]
P'P'VVV	.136	.135	....	....	.113*

[a] Significantly greater than other rotations.

Turning to the effects of the five rotations upon carbon in the soil, Table 4, one sees only a small decrease in the mean for the five plots, from 1.48 to 1.42. The nitrogen in these same plots, however, decreased from .142 to .119, a change several times greater than its standard error. Thus, it seems clear that these rotations did not, in fact, halt the decline in organic matter.

Whether the rotations slowed the decline in organic matter is best tested by a comparison between treatments in the same year. When this comparison is made, one generally sees that the rotations caused higher carbon and nitrogen in the soil than did continuous vegetables, and that the differences among the rotations were slight. The interesting exception occurred in 1960: where the soil had been in vegetables for 2 years, the nitrogen was higher than where it had been in vegetables for 1 year following grass and legume; this difference will also be seen in the spinach grown on the plots.

On the eastern half of the rotated plots the hay was not removed. Hence, more green manure was buried; and if burial of the shoots contributes materially to the benefit from our treatments, the soil of the eastern half should be relatively high in carbon and nitrogen. (Statistically this is tested by examining the mean square for "rotation X half.") In fact, the carbon and nitrogen content of the soil of the unmowed half was never significantly greater than that of the mowed half. For example, in 1960 the mean difference in nitrogen content between the unmowed and mowed halves was only .003 per cent greater in the rotated, than in the continuously cropped, soil. This lack of effect from the shoots left on the plots was observed in nearly all of the characteristics of soil and crop that we shall describe. Therefore, we shall not mention it again except for two characteristics of the crop that were benefitted significantly.

The aggregation of the soil in the plow layer is an index of soil structure, a characteristic generally believed to be a benefit following rotation, a benefit perhaps caused by the added organic matter. In our experiment rotation generally increased the proportion of the soil formed into water stable aggregates in May (Table 6). The different rotations generally did not vary among themselves. This fulfilled the expectation that increased aggregation would follow rotation.

Table 6. Water stable soil aggregates greater than 1/4 mm. in diameter as a percentage of soil

Code	1955	1956	1957	1958	1959	1960
V	24	27	23	22	24	21
AV	....	27	....	25*	....	25*
SV	....	27	....	27*[a]	....	26*
PPVV	37*	35*	....	....	27	26*
RRVV	34*	35*	....	....	26	24*
P'P'VVV	30*	34*	29*	....	....	27*

[a] SV significantly greater than AV.

No relation between organic matter and aggregation was, however, encountered. For example, when the percentage of aggregation was plotted against the percentage of carbon, the 60 observations of 1960 were distributed at random over the graph.

The porosity of the soil between 2 and 4 inches below the surface is a further measure of soil structure. The bulk density of this layer of soil reflects its total porosity. In 1959 and 1960 all rotations significantly decreased the bulk density; densities of 1.50 in 1959 and 1.60 in 1960 in the continuously cropped soil were .08 and .10 greater than the corresponding means for the soils of the rotation plots. In the other years of observation, 1957 and 1958, the .01 and .03 decreases in bulk density were, however, insignificant. In 4 years of observation, the large or non-capillary porosity of the soil was never increased significantly.

The work required to drive the core sampler 2 inches into the soil indicates the hardness of the soil. In 4 years of observation, 1957 through 1960, this measure of hardness was significantly decreased by rotation in 1958 but was not changed significantly at any other time. The soil moisture was approximately equal in all plots at measurement time.

The ability of the soil to store water and release it to roots is a function of structure and, sometimes, of impediments to rapid drainage. The moisture retained in the plow layer 24 hours after a heavy rain indicates this ability (Table 7). In 4 years of observation, 1957 through 1960, the ability to store water in August was always increased by rotation.

Table 7. Moisture storage: percentage moisture in the plow layer 24 hours after a heavy rain

Code	1957	1958	1959	1960
V	15.2	16.5	19.2	16.0
AV	....	17.8*	....	17.9*
SV	....	17.3*	....	18.2*
PPVV	....	....	22.5*	18.7*
RRVV	....	....	21.9*	18.9*
P'P'VVV	16.5[a]	....	....	18.7*

[a] Significantly greater at about 1/5.

If the abilities of the soil to store water and to withhold it from the roots were increased simultaneously, little would be gained. In this experiment, however, the wilting percentage was not increased as much as storage capacity: in 3 years of observation, rotation always increased the available moisture holding capacity; and the increase was often significant (Table 8). Whether or not these changes in structure, indicated by several means, were in fact beneficial is tested by analysis of the yields of early spinach and late cabbage.

Table 8. Available moisture holding capacity: moisture storage less wilting percentage

Code	1957	1958	1959
V	9.2	10.7	13.8
AV	....	11.9[a]	....
SV	....	11.4[a]	....
PPVV	....	....	16.2*
RRVV	....	....	15.7*
P'P'VVV	10.3	....	....

[a] Significantly greater than mean for V at about 1/10.

THE YIELDS

The yield of spinach could have reflected the benefit of rotation on 20 occasions during the 7 years of observation (Table 9). Yields of this early crop were, in fact, increased 14 times, unchanged 4 times, and decreased twice. Only three of these changes were significant: relative increases of 7/12 in 1954 and 2/12 and 3/12 in 1960. These three instances were not all associated with a single rotation.

Special interest is aroused, nevertheless, by the behavior of the 4-year rotations in 1960: they produced an outstanding increase in the nitrogen content of the plow layer (Table 5), and an outstanding increase in spinach yield (Table 9).

Table 9. Yield of spinach, cwt./A.

Code	1954	1955	1956	1957	1958	1959	1960
V	12	12	13	12	17	17	12
AV	19*	....	12	....	19	....	13
SV	13	....	14	....	17	....	12
PPVV	....	14	15	....	....	18	14*
RRVV	....	13	13	....	....	15	15*
P'P'VVV	....	14	16	12	....	....	13

Also, we here encounter one of the two observed benefits from leaving on the land the hay grown in rotation: the halves of the 4-year rotation plots on which the hay was left in 1957 and 1958 produced in 1959 a significant 2.2 cwt. per acre more than the halves on which hay was harvested; this difference is measured relative to the difference between halves of the continuously cropped plots.

The yield of cabbage also could have reflected the benefit of rotation on 20 occasions (Table 10). Yields of this late crop were in fact increased 14 times, unchanged 6 times, and never decreased. Nine of these changes were significant: relative increases of about 4/33 in 1954, 1958, and 1960. No particular rotation was particularly beneficial; all occasionally proved beneficial. The 4-year rotations, that were particularly effective in 1960 in increasing both nitrogen in the soil and spinach yields, were not outstanding in their benefit to the later cabbage of that season.

Table 10. Yield of cabbage, cwt./A.

Code	1954	1955	1956	1957	1958	1959	1960
V	36	21	31	36	31	31	32
AV	40*	....	32	....	33*	....	34*
SV	41*	....	31	....	37*	....	36*
PPVV	....	25	33	....	....	31	36*
RRVV	....	26	31	....	....	31	36*
P'P'VVV	....	23	31	36	....	....	36*

Any cause and effect relation between the organic matter in the soil and the growth of the crop was sought by plotting the yield of spinach against the carbon content of the soil. A trend was evident but not distinct, accounting for a significant but small 8 per cent of the variation in the spinach yields. The relation between spinach yield and the nitrogen content of the soil was even less distinct. Finally, we could not discern any relation between aggregation and spinach yields. Having seen the effects of rotation upon the quantity of produce, we now examine the effect upon quality.

THE QUALITY OF VEGETABLES

The spinach grew in the soil during the 2 months immediately after the burial of the green manure, and there was ample opportunity for the crop to be influenced by that buried organic matter.

The toxicity of the oxalic acid makes it an important constituent of spinach (12). Its concentration in the leaves grown upon the continuously cropped soil was not different from the concentration in the leaves grown on the rotation plots that had a higher organic matter content (Table 11). About one-fifth of the oxalic acid could have been combined with the calcium found in the foliage, and the proportion thus neutralized was not affected by rotation.

Vitamin content of samples of the spinach leaves was determined by Dr. Lester Hankin. He assayed the leaves grown in 1960 on one of the V plots that had grown vegetables for 8 years and those grown on one of the AV rotation plots. The two samples of dried leaves contained 8 and 9 μg thiamine and 23 and 21 μg riboflavin per g.; these differences cannot be considered significant, and we have no evidence that rotation changes vitamin content.

Nitrogen is not so clearly an ingredient of quality, but it is important in both the nutrition of the plant and its vital processes; presumably it is important to the consumer as well. The concentration of nitrogen in the leaves was significantly increased by rotation on 6 occasions out of 10 observed (Table 11). On these same 10 occasions, yield was significantly increased only twice.

Table 11. Composition of spinach in percentage of dry weight

Code	Nitrogen 1957	Nitrogen 1958				Nitrogen 1959				Nitrogen 1960				Iron 1960	Calcium 1960	Oxalic acid 1960
	Total	Total	Protein	NO_3	NH_3	Total	Protein	NO_3	NH_3	Total	Protein	NO_3	NH_3			
V	3.31	3.25	2.50	.13	.34	3.91	2.40	.37	.56	4.96	2.24	.59	.54	.120	.62	7.7
AV	......	3.91*	2.67	.41*[a]	.34	......	......	......	......	4.84	2.46	.59	.50	.110	.64	7.9
SV	......	3.72*	2.58	.31*	.32	......	......	......	......	4.95	2.29	.67	.53	.114	.68	7.6
PPVV	......	......	......	......	......	4.12*	2.46	.67*	.63	5.29*	2.26	.89*	.51	.114	.50[a]	7.6
RRVV	......	......	......	......	......	4.12*	2.48	.59*	.56	5.12*	2.32	.63	.54	.108	.52[a]	7.5
P'P'VVV	3.37	......	......	......	......	......	......	......	......	4.98	2.34	.70	.54	.110	.57	7.5

[a] Significantly different from other rotations.

The other exceptional benefit from leaving on the land the hay grown in rotation is this: the spinach grown on the half-plots that retained hay was 0.13 per cent higher in nitrogen than on the halves from which the hay was removed; this excess is measured relative to the difference between halves of the continuously cropped plots.

The distribution of nitrogen into protein, nitrate, and ammonia is shown in Table 11. Evidently the change in nitrogen concentration is due to a change in the nitrate nitrogen, not to a change in protein or ammonia.

The nitrogen concentration in cabbage also was examined (Table 12). Like the concentration of nitrogen in the earlier spinach, the concentration was also increased in the cabbage grown on the rotation plots.

Table 12. Nitrogen composition of cabbage in percentage of dry weight

Code	1958	1959	1960
V	2.30	2.34	2.28
AV	2.42	....	2.50*
SV	2.45	....	2.29*
PPVV	....	2.81*	2.41*
RRVV	....	2.42	2.33*
P'P'VVV	....	....	2.41*

Concentration of minerals in the spinach leaves of 1960 is another indicator of quality. The concentration of iron was unaffected (Table 11). The calcium was decreased significantly by the two 4-year rotations that were outstanding in their ability to increase both nitrogen in the soil and spinach yields.

DISCUSSION

The organic matter of the continuously cropped plots decreased as expected. A variety of organic materials and their turnover, rather than their accumulation, seem important characteristics of soil organic matter (3); therefore, the nature of the material lost from the soil is interesting. Our only information upon composition is the relative carbon and nitrogen content of the soil. These data are conveniently analyzed in terms of logarithms of concentrations. The ratio of carbon to nitrogen was 10.00 in 1953 and rose significantly to 11.45 in 1960, indicating that cropping to vegetables caused the organic matter in the soil to become poorer in nitrogen.

The rise in C/N observed during this cultivation is contrary to the conventional view: the loss of carbon dioxide is greater than the loss of nitrogen during cultivation, and hence C/N falls. However, a rise can, in fact, occur. For example, 10 years of tobacco growing increased C/N in Merrimac sandy loam in a lysimeter from 15.4 to 16.7 (16). Further, 42 years of a variety of crops increased C/N in a Bridgehampton soil from 9.7 to 14.2 (13). Clearly, in these soils that are both low in organic matter and easily leached, cropping can cause the loss of nitrogen to be relatively greater than the loss of carbon.

From what level has the organic matter fallen? And since it is still falling, how low will it fall? An indication of the content found by the first farmers

when they arrived over three centuries ago is found in Lunt's analysis of a forested Cheshire soil: the 6-inch A horizon contained 2.87 per cent carbon and .222 per cent nitrogen (14). Assuming that this forested soil represents the virgin soil and that a year of cultivation reduces the carbon in the soil by 1 per cent of itself, the change from the 2.87 per cent carbon in the forested soil to the 1.22 per cent in our continuous vegetable plot in 1960 (Table 4) is equivalent to 86 years of cultivation. This same assumption of a 1 per cent per year loss also permits a discussion of the future: the equivalent of 30 years of cultivation will reduce the 1.22 per cent carbon content of 1960 to 0.9 per cent; about the level in an intensively cultivated and unfertilized tobacco soil of the Connecticut Valley (16) and in England's well-known Broadbalk Field after 50 continuous years in wheat (21, p. 271).

The rotations increased the organic matter in the soil, relative to the untreated check, without completely halting the year-to-year decline. The increase relative to the check was not large; for example it was about one-sixth in 1960. All this was expected from the experience reviewed in the literature.

The durability of the increase in organic matter, as well as the increase in yield, was surprising. The 4-year rotations increased both organic matter and yields in the second year of vegetables, 1960, as well as in the year of burial, 1959. The experience with large quantities of filter press cake from sugar-cane, already cited, and the observation that incorporating in soil the equivalent of a ton per acre of shoots will in time actually reduce soil organic matter (7) did not lead us to expect this durability of the increase. On the other hand, Tenney and Waksman (26) did find one-fourth to one-half of the dry material of alfalfa still present after 405 days of warm, moist incubation. And in Alabama, green manure did produce increased yields into the second year of vegetables (30). We suggest that the difference between our experience in the field and the experience with filter cake or the incubation of shoot and soil in the laboratory may be due to two things: During much of the year, the soil is cooler and decomposition slower in an Alabama or Connecticut field than in a Puerto Rican field or in a laboratory; further, the roots of the rotation crop may contribute to the soil a more resistant material than either the filter cake or the shoots. In any event, we must conclude that the increased organic matter and yields following rotation can persist into a second year.

The observation that the burial of shoots does not increase the benefits already realized from the growth and decay of the roots of the rotation plant clearly verified our expectation based upon the literature reviewed: either the burial of shoots is of no benefit because the *growth* of grass and legume roots, not the burial of the organic matter, is the essential ingredient; or the addition of excessive residues is fruitless because an equilibrium level of soil organic matter is not easily exceeded; or the easily decomposed shoots add little to the soil organic matter and may even enhance decomposition of the native soil organic matter (7). Thus we have no evidence that the burning or removal of the forage from a rotation crop would be disadvantageous.

The cause of increased yield following rotation has not been clearly established by any of our observations: carbon, nitrogen, and aggregation of the soil all failed to be correlated with yield. Nevertheless, a clue to the cause can be seen in the high nitrate concentration of spinach grown following rotation, which indicates a more luxurious nitrogen supply for this spinach than for the spinach grown on soil continuously planted to vegetables. Further, the observed

1 to 2 per cent increase in the available moisture storage capacity added a 1- to 2-day supply of moisture for the plants and was certainly beneficial.

The 7 years of experience represented by the tables of yields is short compared, for example, to the 30 years enjoyed in weather records. Nevertheless, because the weather of these 7 seasons was variable, our experience should provide an inkling of the benefits from rotation that would be encountered in a generation. Since the rotations were roughly equivalent in their benefits, they can be averaged. Giving each season's experience equal weight, we find that rotation increased the yield of spinach about 1.2 above the 12.8 cwt./A. produced by continuous cropping; rotation increased the yield of cabbage 2.5 above the 31.1 cwt./A. produced by continuous cropping. These increases, observed in the past and expected in the future, permit an approximate economic analysis of the practice of rotation versus continuous cropping to vegetables. One must ask, "How great is the benefit of a one-tenth increase in yield compared to the cost of idle land and production of green manure for burial?"

The changes in the quality of the vegetables are disappointingly small and furnish scant basis for discussion.

Adopting yield as the ultimate criterion of success, the results of our studies can be viewed as either bad news or good. Since we did not discover a rotation that materially increased production above that of intensive and continuous vegetable growing with commercial fertilizer, the news may be considered bad.

If we ask, instead, whether efficient but intensive continuous vegetable growing is destroying the fertility of the soil, then the news is good. The results from the old and well-known Morrow Plots of Illinois reinforce our own: after more than 50 years of continuous corn growing, yields had fallen to only about one-half the yield obtained where a corn-oats-clover rotation was followed. Then lime and commercial fertilizer were added to both fields; and the yields on the plots that had grown corn continuously increased three-fold, reaching four-fifths the productivity of the rotated plots (9).

Surely this is good news. If the nutrient elements are added from mines and factories, vegetables—like corn—can evidently be grown continuously without a large decrease in productivity and with the savings that follow from the use of the smallest possible acreage.

These experiments were begun under the leadership of C. L. W. Swanson, then Chief Soil Scientist of this Station. The suggestions of G. G. Curtis, County Agent, Middlesex County, inspired the investigations. Since the resignation of Dr. Swanson in 1956, the work has been carried forward by the authors of this Bulletin.

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