THE CARBON-NITROGEN RATIOS IN HAWAIIAN SOILS

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N.B.

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INTRODUCTION

The status of nitrogen and carbon in the soil involving both actual content and ratio has been recognized to correlate with crop production. In many cases emphasis has been placed on information derived from the carbon-nitrogen ratio and corresponding quantitative values of either carbon or nitrogen.

Decomposition of plant residues, from which the soil organic matter originates, is accompanied by a narrowing of the carbon-nitrogen ratio. As decomposition slows down an equilibrium value is approached and the value usually attained is about 10 to 12:1. This equilibrium value is normally quoted for soils of the temperate regions.

It is easily understood that the carbon:nitrogen value in the soil is a function of the climate more than it is of the other soil forming factors. The climatic conditions of any area greatly influence both the rate of addition of plant residues to soil and the rate of decomposition of that plant material. In Hawaii great changes in rainfall can be found within very short distances. The temperature changes in Hawaii are mainly a function of the elevation, decreasing about 3 degrees fahrenheit for each 1000 feet rise in elevation in local areas. In this respect Hawaii offers a good opportunity to study the organic matter as a function of rainfall because of the small change in temperature relative to the changes in annual rainfall.

The objective of this research is to determine quantitatively carbon, nitrogen, and the carbon-nitrogen ratios of the soils of Hawaii and to show each in relation to the annual rainfall.

REVIEW OF LITERATURE

The carbon-nitrogen ratio did not initially take the form of C/N directly but as pointed out by Jacks (5) various ratios showed up, such as 100N/C, N/C and finally C/N. McLean (9) found that the carbon-nitrogen ratio is normally about 10-12:1; however, there is a wide difference among the soils of the world. He further states that, ". . . It is probable that climatic conditions play a dominant part in determining the ratio for soils in any particular area. . . . It seems that soils in warmer climates have higher ratios than soils in cool climates and that the C/N ratio is specific for each particular region".

It is known that the climate not only affects the soil organic matter but that soil formation is effected by the climate. It should be pointed out that climate is not the only factor affecting soil organic matter. Jenny (6) in his study of the relation between temperature and soil nitrogen found that nitrogen decreased with increase in temperature. This work was done in the temperate regions of North America. A. L. Dean (3) found that the relation between temperature and nitrogen in Central United States could not be extended to include Hawaii. In fact, Dean states that, "On the basis of soil nitrogen, Hawaii belongs just south of the Canadian boundry instead of south of the Tropic of Cancer". It is interesting to note that A. L. Dean (3) also found that the carbon-nitrogen ratio in most Hawaiian soils was below 10:1 and more nearly 8:1.

L. A. Dean (4) studied the effect of rainfall on carbon and nitrogen contents and carbon-nitrogen ratios of Hawaiian soils and showed a significant relationship. His investigations gave carbon-nitrogen ratios of nearly 12:1 which is more consistent with what would be expected from earlier workers. He also observed that both carbon and nitrogen increased with rainfall and elevation and that considering soils of constant carbon contents, the nitrogen decreased with increasing rainfall. This observation leads to the conclusion that the carbon-nitrogen ratio would then also increase with rainfall. The results of the work of Ayres (1) are similar to those obtained by L. A. Dean. He found that for cultivated soils the organic matter level for drier soils, those that received an average of 25 to 40 inches of annual rainfall, was bout 2 to 6 percent and for wetter soils, those that received 150 to 180 inches of annual rainfall, was about 10 to 20 percent. He also found that for these ranges in precipitation the carbon-nitrogen ratio varied from 9 to 20.

Jenny (7, 8) attempted to resolve the conflicting reports between his earlier work (6) and that of Dean (3), Dean (4), Ayres (1), and others. He obtained results in Columbia, South America that were similar to those obtained for similar conditions in Hawaii, namely higher nitrogen with increasing rainfall and decreasing temperature and the carbon-nitrogen ratios increasing as log of the rainfall. Jenny (8) concludes that in the tropical regions, favorable climatic conditions and high annual rates of fixation of nitrogen due to large numbers of legumes in the tropics, are the primary causes of luxuriant vegetation.

He also states that the decomposition of the forest floor that rests on the mineral soil proceeds at a rapid rate and a considerable part of the decomposition products infiltrates into the mineral soil. Decomposition within the mineral soil appears to be slow. Accordingly, humus rapidly accumulates to a high level.

Ayres (1) agrees with Jenny that there is a large amount of native vegetation in the high rainfall areas of the humid and semi humid tropics and that the high organic matter content in the soil is due not only to luxuriant native vegetation but also to slow decomposition. He attributes the slow decomposition within the soil to excessive soil moisture and a low pH value which hinders bacterial activity.

DESCRIPTION OF SOIL SAMPLED

The soils for this study were selected to represent the major great soil groups and important soil series within these great soil groups. Most of the samples came from the island of Oahu. Two soil series, the Hilo and Puhi, came from Hawaii and Kauai respectively. All samples were selected on level to gently sloping topography. Four samples, one from each of four areas, were taken for each soil series. When possible, samples of virgin soils were taken. In some cases due to the extensive cultivation of the series, this was not possible. In this study only the surface soil 0 to 8 inches was used. Table I lists the soils sampled along with the rainfall and elevation at each sampling site. The physical properties of the soils used are described by Cline (2) in the Soil Survey of the Territory of Hawaii. The location of the samples from Oahu are shown on the map in figure 1.

TABLE I THE LIST OF SOILS SAMPLED INCLUDING ANNUAL RAINFALL AND ELEVATION OF EACH SAMPLE

Great Soil Group	Soil Series	Sample & Map. No.	Rainfall (In Inches)	Elevation (In feet)
Low Humic Latosol	Molokai	1*	28	120
		2*	27	150
		3*	31	320
		4	23	200
	Waipahu	5*	22	70
		6*	21	40
		7*	26	80
		8*	25	90
	Lahaina	9	27	540
		10	27	170
		11	27	140
		12	30	340
	Wahiawa	13*	45	920
		14*	46	480
		15*	45	480
		16*	50	440
	Kahana	17*	64	640
		18*	60	660
		19	56	610
		20*	52	640
Humic Latosol	Paaloa	21*	45	1000
		22*	68	1020
		23*	70	1200
		24*	75	840
	Kaneohe	25*	83	280
		26*	90	280
		27*	70	130
		28*	83	320
Hydrol Humic Latosol	Hilo	29*	148	100
		30*	200	1320
		31*	140	110
		32*	140	110
	Koolau	33*	98	1050
		34	95	1180
		35*	90	1280
		36*	83	1360

TABLE I (continued) THE LIST OF SOILS SAMPLED
INCLUDING ANNUAL RAINFALL AND ELEVATION OF EACH SAMPLE

Great Soil Group	Soil Series	Sample & Map No.	Rainfall (in inches)	Elevation (in feet)
Humic Ferruginous Latosol	Kolekole	37*	37	840
		38*	32	840
		39*	30	760
		40*	28	720
	Puhi	41	80	280
		42	50	380
		43	60	380
		44	55	400
Dark Magnesium Clay	Lualualei	45*	25	120
		46	20	70
		47*	18	60
		48	18	60
Grey Hydromorphic Soil	Honouliuli	49	19	30
		50	18	60
		51	34	20
		52	26	20

*virgin soils

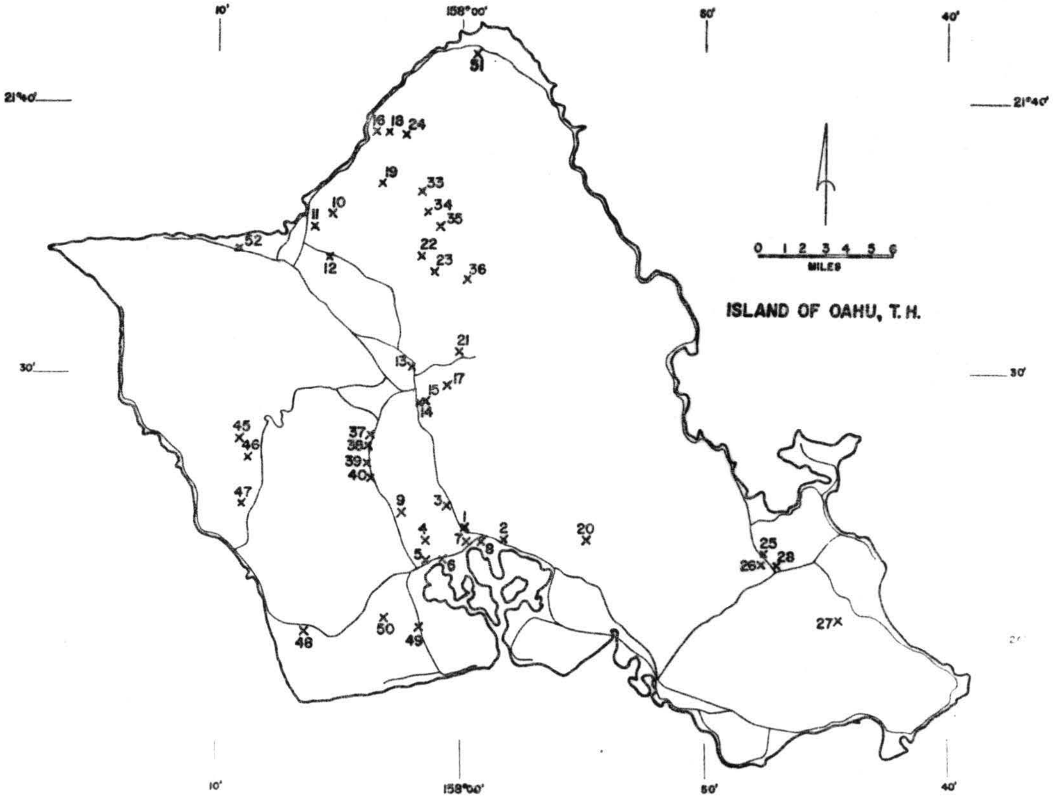

FIGURE I THE LOCATION OF SAMPLING SITES ON THE ISLAND OF OAHU.

EXPERIMENTAL PROCEDURE

Preparation of Soil Samples: The bulk soil samples were air dried for a period of two weeks. Any large undecomposed organic matter, such as roots of living plants and surface trash, was removed as this was not considered part of the soil organic matter. The entire sample was then ground to pass a 20 mesh screen. This included any rock fragments that were present within the soil. The ground sample was then thoroughly mixed. A small portion was removed and oven dried at 110° C for at least 24 hours. The samples were then analyzed for carbon and nitrogen in duplicate, and averaged.

Carbon: Carbon was determined following the dry combustion method described by Piper (10) with the modification that pure bottled oxygen was blown through the combustion tube rather than air being drawn through.

Nitrogen: Nitrogen was determined by the Kjeldahl method for soil nitrogen as described in the Methods of Analysis of the Association of Official Agricultural Chemists (12).

RESULTS

The results of the analyses for carbon and nitrogen in the 52 soils sampled are shown in table 2. The carbon-nitrogen ratios calculated from the carbon and nitrogen content are also shown. Plots of carbon vs. rainfall, nitrogen vs. rainfall, and carbon:nitrogen vs. rainfall are presented in figures 2, 3, and 4 respectively. A correlation analysis of carbon and rainfall indicated a correlation coefficient of 0.847 which was highly significant. The equation of the regression line of carbon on rainfall is $C = 0.063R - 0.105$; this line is indicated in figure 2. A multiple regression of carbon on rainfall and elevation was also studied. A "t" test of the β coefficients showed the "t" of 10.748 for b of carbon on rainfall to be highly significant with a probability of getting a higher value of less than 1 in 1000 and the "t" of 0.260 for b of carbon on elevation to be non-significant with a probability of getting a higher value of more than 5 in 10. The mean carbon content was 3.35 ± 0.42 percent.

The correlation analysis between nitrogen and rainfall gave a correlation coefficient of 0.796 which is highly significant. The equation of the regression line of nitrogen on rainfall is $N = 0.003R + 0.061$. This line is indicated on figure 3. A multiple regression of nitrogen on rainfall and elevation was studied. A "t" test of the β coefficients gave a "t" of 7.237 for b of nitrogen on rainfall which was highly significant with a probability of getting a

TABLE II CARBON, NITROGEN, AND CARBON-NITROGEN RATIO OF 52 HAWAIIAN SOILS.

Great Soil Group	Soil Series	Sample No.	Carbon %	Nitrogen %	C/N
Low Humic Latosol	Molokai	1*	1.71	0.148	11.54
		2*	1.42	0.152	9.37
		3*	1.16	0.142	8.16
		4	1.55	0.157	9.89
	Waipahu	5*	1.28	0.123	10.42
		6*	1.97	0.146	13.48
		7*	1.41	0.148	9.53
		8*	1.21	0.105	11.51
	Lahaina	9	2.15	0.204	10.54
		10	1.99	0.186	10.68
		11	1.79	0.172	10.39
		12	2.03	0.214	9.50
	Wahiawa	13*	1.37	0.118	11.42
		14*	3.25	0.338	9.61
		15*	2.84	0.310	9.16
		16*	4.80	0.403	11.92
	Kahana	17*	3.34	0.285	11.68
		18*	3.88	0.288	13.46
		19	1.82	0.194	9.39
		20*	4.42	0.238	18.56
Humic Latosol	Paaloa	21*	3.41	0.220	15.52
		22*	3.44	0.238	14.43
		23*	3.45	0.308	11.21
		24*	3.15	0.201	15.66

TABLE II (continued) CARBON, NITROGEN, AND CARBON-NITROGEN RATIO OF 52 HAWAIIAN SOILS.

Great Soil Group	Soil Series	Sample No.	Carbon %	Nitrogen %	C/N
Humic Latosol	Kaneohe	25*	3.91	0.229	17.06
		26*	5.37	0.351	15.30
		27*	3.25	0.270	12.03
		28*	4.77	0.331	14.40
Hydrol Humic Latosol	Hilo	29*	5.89	0.334	17.62
		30*	17.02	0.976	17.44
		31*	8.71	0.561	15.53
		32*	13.13	0.790	16.62
	Koolau	33*	3.35	0.179	18.74
		34	3.45	0.214	16.13
		35*	3.71	0.252	14.73
		36*	3.40	0.204	16.65
Humic Ferruginous Latosol	Kolekole	37*	4.24	0.254	16.69
		38*	2.77	0.234	11.83
		39*	4.08	0.298	13.71
		40*	5.68	0.380	14.95
	Puhi	41	3.83	0.269	14.24
		42	3.12	0.230	13.55
		43	3.10	0.256	12.11
		44	3.26	0.292	11.15
Dark Magnesium Clay	Lualualei	45*	0.75	0.067	11.13
		46	1.00	0.088	11.39
		47*	0.88	0.088	9.94
		48	1.44	0.090	15.96

TABLE II (continued) CARBON, NITROGEN, AND CARBON-NITROGEN RATIO OF 52 HAWAIIAN SOILS.

Great Soil Group	Soil Series	Sample No.	Carbon %	Nitrogen %	C/N
Gray Hydromorphic Soil	Honouliuli	49	0.47	0.067	6.96
		50	1.53	0.098	15.62
		51	2.16	0.164	13.18
		52	1.32	0.133	9.96

*virgin soils

higher value less than 1 in 1000, and the "t" of 0.018 for b of nitrogen on elevation to be non-significant with a probability of getting a higher value of more than 5 in 10. The mean nitrogen content was 0.245 ± 0.031 percent.

The plot of carbon:nitrogen vs. rainfall (figure 4) indicated a curvilinear relationship. Therefore, a correlation analysis between log carbon:nitrogen and log rainfall was made. This gave a correlation coefficient of 0.585 which was highly significant. The equation of the regression line of log carbon: nitrogen on log rainfall is $\log C/N = 0.217 \log R + 0.742$; this line is indicated on figure 4. A multiple regression of log carbon:nitrogen on log rainfall and elevation was also studied. A "t" test of the β coefficients showed the "t" of 3.955 for b of log carbon:nitrogen on rainfall to be highly significant with probability of getting a higher value of less than 1 in 1000, and the "t" of 1.039 for b of log carbon:nitrogen on elevation to be non-significant with a probability of getting a higher value of between 2 and 4 in 10. The mean log carbon: nitrogen was 1.100 ± 0.023.

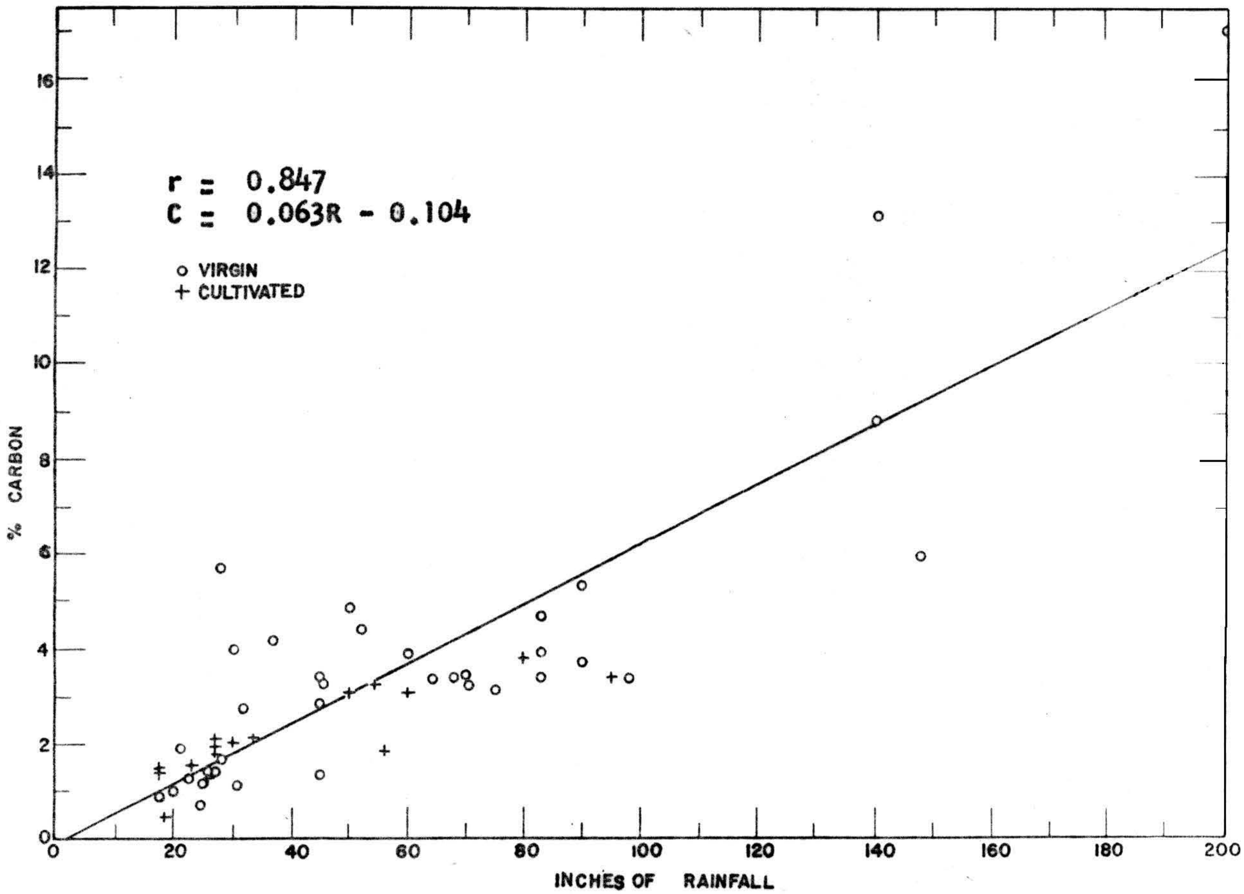

FIGURE 2 RELATIONSHIP BETWEEN CARBON CONTENT AND ANNUAL RAINFALL OF 52 HAWAIIAN SOILS.

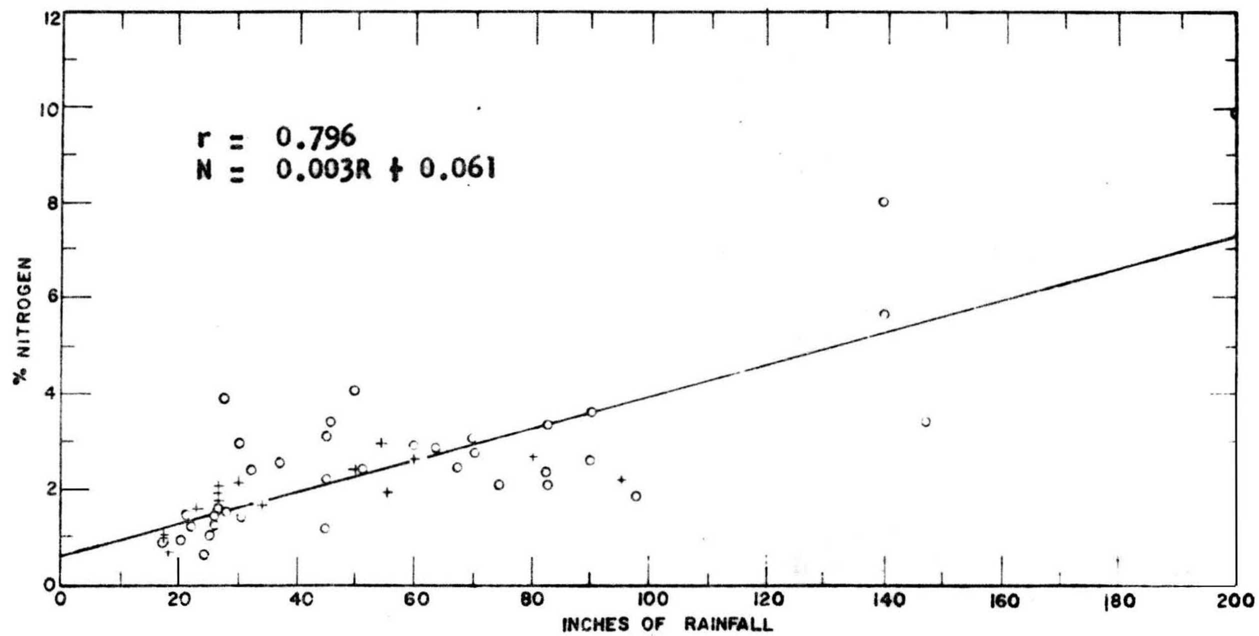

FIGURE 3 RELATIONSHIP BETWEEN NITROGEN CONTENT AND ANNUAL RAINFALL OF 52 HAWAIIAN SOILS.

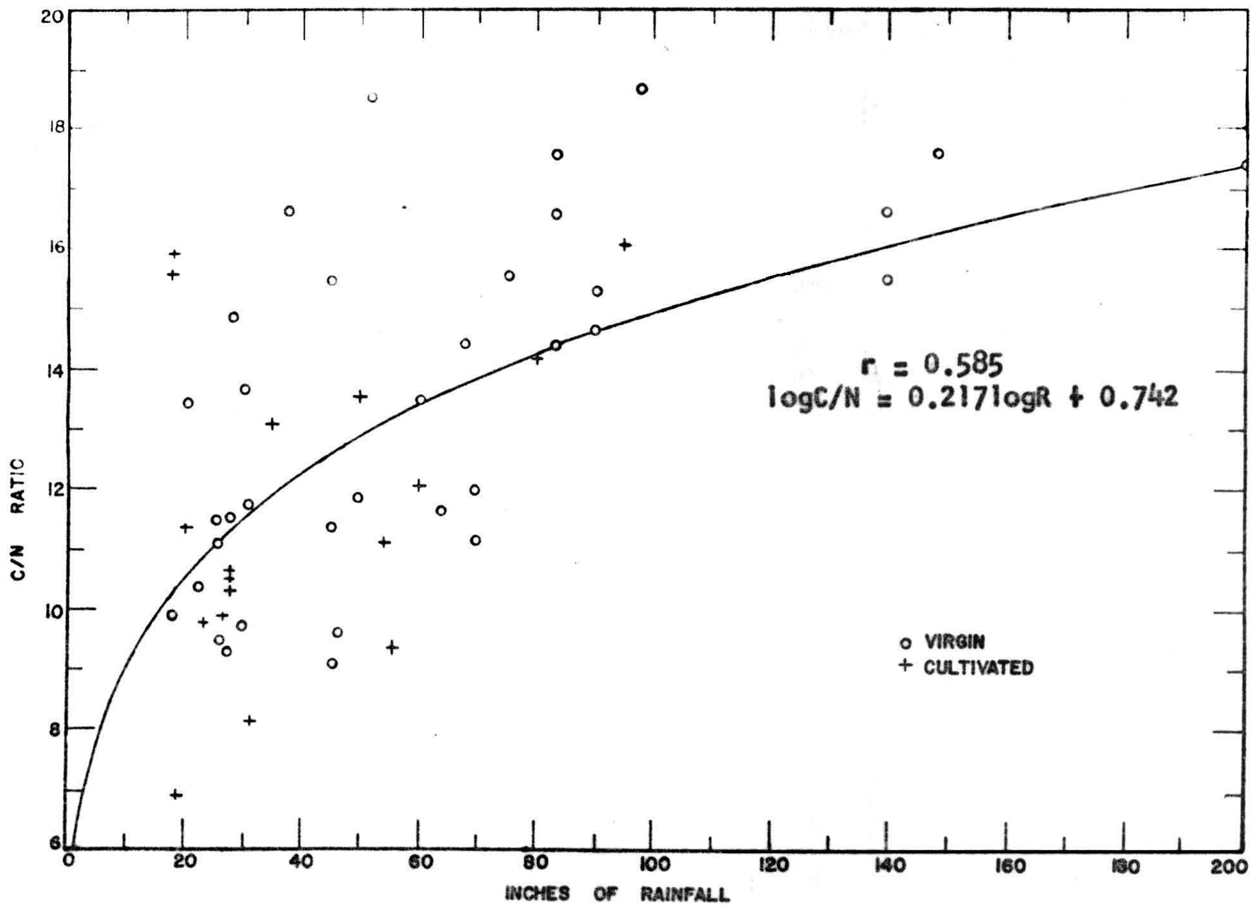

FIGURE 4 RELATIONSHIP BETWEEN CARBON-NITROGEN RATIO AND ANNUAL RAINFALL OF 52 HAWAIIAN SOILS.

DISCUSSION OF RESULTS

The organic matter content of the soil as indicated by the carbon content, increases with increasing rainfall. If the mean annual temperature decreases with increasing elevation there is no significant change in carbon content with temperature. In small areas there is a highly significant correlation between rainfall and elevation. In the area covered by this study the correlation was only significant. In this respect one can expect the organic matter in the soil to increase with increasing elevation. This agrees with Ayres (1) and Jenny (8) that the natural vegetation is heavier and that the decomposition within the soil is impeded due to the higher amounts of water contained in these soils.

As shown in figure 2 the carbon content, which is a measure of the organic matter content, is higher in the cultivated soils than in the virgin soils in the regions of rainfall below about 30 inches. Above about 50 inches of rainfall the reverse seems to be true, that is, the carbon content is less in the cultivated soils than in the virgin soils. Under cultivation in the low rainfall regions more organic matter is returned to the soil under irrigated crops than is returned to virgin soils. In higher rainfall regions the opposite appears to be true. That is, less organic matter is added to the surface of the cultivated soils then to the virgin soils, and cultivation helps to aerate the soil and aid the decomposition of the existing soil organic matter.

Nitrogen also increases with rainfall but at a slower rate than does carbon. This phenomenon is to be expected because as the rainfall increases, the vegetation becomes more luxuriant and larger amounts of fresh material are added to the surface. Decomposition under these wetter conditions is also slower. Even though the decomposition is slower the nitrogen that is mineralized is leached more rapidly in the high rainfall regions. Therefore, it is to be expected that the carbon-nitrogen ratio will increase to equilibrium values that will be closer to the carbon-nitrogen ratio of the fresh plant material. It can be discerned then that with increasing annual rainfall not only does nitrogen content increase but also the carbon-nitrogen ratio. The fact that the carbon-nitrogen ratio does increase and approach a maximum is indicated in figure 4. More data in the area of 100 to 200 inches of rainfall would show this more clearly.

Figure 3 indicates a similar characteristic for nitrogen of cultivated and virgin soils as figure 2 does for carbon. Since both carbon and nitrogen are affected similarly the carbon-nitrogen ratio should not be affected and the carbon-nitrogen ratio for cultivated soils should be no different than that for virgin soils. The graph in figure 4 shows that there is no appreciable difference in the carbon-nitrogen ratio between cultivated and virgin soils. The results of Ayres (1) for carbon-nitrogen ratios in the high rainfall area agree very well with those shown in figure 4.

In the regions of high rainfall the high carbon-nitrogen ratio does not seem to affect adversely the growth of native vegetation. A large proportion (probably over 40%) of these tropical and semi-tropical plants are legumes and therefore are partially able to "fix" their own nitrogen and supply nitrogen to the adjacent non-leguminous plants. This aids also in the build up of organic matter to high levels in many of these soils. Ten to 20 percent or higher organic matter is common in these tropical rain forest type soils.

There are then, in the rain forest type soils of the tropics, equilibrium values of carbon-nitrogen ratios that will not adversely affect plant growth. The organic matter content will not be maintained in the cultivated soils at the same level as in the virgin soils because of the added aeration due to manipulation of the soil. Also most crop plants will not supply sufficient nitrogen to maintain the organic matter at a high level.

SUMMARY

Both carbon and nitrogen increase with increasing rainfall. The cultivated soils in regions of rainfall below 30 inches have more carbon and nitrogen than the virgin soils. In regions of rainfall above 50 inches the cultivated soils have less carbon and nitrogen than corresponding virgin soils. This phenomenon is associated with the amounts of plant residues returned to the soil by crops or native vegetation.

The carbon-nitrogen ratio increases logarithmically with increasing rainfall and tends to approach a maximum. There is no difference in the carbon-nitrogen ratio of cultivated and virgin soils of similar rainfall areas. The large number of leguminous plants is probably the main reason why the native plant growth is not hindered by the high carbon-nitrogen ratio and subsequent nitrogen availability.

The high amounts of organic matter in the soils of the high rainfall areas aid in the maintenance of the soil structure which allows large amounts of water to enter the soil. This large quantity of water produces a semi anaerobic condition that hinders decomposition and maintains the organic matter and the carbon-nitrogen ratio at high levels.

There was no correlation between the elevation and carbon content, nitrogen content, or carbon-nitrogen ratio.

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