Final report on studies of nutrient cycling on white and black water areas in Amazonia

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Abstract

Studies were conducted near Manaus, Brazil in cooperation with INPA to try to establish how nutrient cycling influences the formation of black water and white water. The studies measured the rate of decay of **Caryocar villosum** leaves on spodosol and oxisol terrestrial and aquatic sites when the leaves were untreated, and treated with a bacteriostat, or insecticide or fungicide. It also measured litter, animal populations, and the elemental content of ten biologically important elements in soils and decomposing litter. Results show considerable differences in the rates of decay and the agents and end products of decay which indicate that black water and white water formation are closely tied to the rate and type of decay and to basic soil types and their associated vegetation, except for the sediments in white water.

INTRODUCTION

It was observed long ago that the areas of Amazonia which generate black water rivers have white sands which have undergone podzolization, while those which produce white water rivers have oxisols from which silica has been leached. The two processes, podzolization and laterization (producing oxisols in the new terminology) differ primarily in the pH of the leaching solution which reaches the soil, and the oxidation conditions. Spodosols are thought to be produced when the leachate from the litter into the soil is acid, thus making iron and aluminum readily soluble and hence leachable. Oxisols are produced when the leachate passing from the litter into the soil is more nearly alkaline so that silica is solubilized and leached to deeper horizons. The extensive differences between black water and white water (Klinge, 1967; Williams *et al.*, 1972) are thought to arise from differences originating with these two soil forming processes, and some differences of parent material.

The suspended material characteristic of white water is carried by these streams because of the nature of the clays that form on the oxisols which generate white water. However, clays from black water areas from the spodosols will turn the water milky white when these clays are soaked for a long period of time. White water per se, often has black water in it and swampy areas on oxisols may give rise to black water. Also, the leaves of many types of tropical and temperate vegetation will produce black water of one type in acid conditions and black water of another type in alkaline conditions.

Since the precipitation which falls over forests on oxisols and spodosols is about the same in pH (4-5), the differences in the pH of the leaching solution must arise as a result of the chemical changes occurring on the leaf and bark surfaces during throughfall and stemflow, and within the litter itself during decomposition. The differences between the two major soil groups (oxisol and spodosol) in the tropics, and their resultant water chemistry have never been closely tied to the chemical processes which dominate litter decomposition. This study attempted to determine whether black water is actually generated on land or under water, and what the major decomposer groups were on spodosols and oxisols as well as in black and white waters in Amazonia.

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Many studies have dealt with the mysteries of black and white water (Brinkman, 1970 and personal communication; Fittkau, 1967; Sioli *et al.*, 1969; Schmidt, 1970). In the last ten years, many studies of water quality have been conducted to try to describe the water of this huge network of rivers. Other studies have dealt with the soils (Sioli, 1966) and the sedimentary loads (Gibbs, 1967). For this reason, this study did not concentrate on water quality but on decomposition and nutrient cycling.

This research was sponsored by the Instituto Nacional de Pesquisas da Amazônia (INPA) and was conducted from Manaus, Brazil. Some of the analyses were done at the School of Forestry, University of Montana, Missoula, Montana. The study site for spodosols was west of Manacapuru on the Rio Manacapuru, while that for the oxisols was a soil of intermediate character on the new Punta Negra road out of Manaus, Brazil.

In this report, "igapó" refers to flooded areas with black water, while "varzea" refers to periodically flooded white water areas adjacent to oxisols. "Campina" refers to a special type of forest (10 m) rich in epiphytes and growing on white sands (spodosols).

METHODS

LITTER DECOMPOSITION — TERRESTRIAL AND AQUATIC

Leaves of *Caryocar villosum* (Aubl.) Pers. (Pequia) were dried at 100° C. for 24 hours and packaged in 2 mm nylon mesh bags stitched with nylon line. This genus was selected for testing since it has species in or near both sites. Three hundred and twenty bags were prepared with one dry leaf per bag and were numbered. These bags were subjected to the following treatments:

A. Black Water — Terrestrial, Spodosol 5 bags each month for four months.
   Control (distilled water)
   Fungicide (10 g Benlate, 10 g Dithane in 5 L water)
   Bacteriocide (5 g streptomycin sulfate in 5 L water)
   Insecticide (100 m "Detefon" (1) in 5 L water)

B. Black Water — Aquatic (Igapó) (beneath 1-3 m of water)
   Control (Control and treatments the same as under A)
   Fungicide
   Bacteriocide
   Insecticide

C. White Water — Terrestrial, Oxisol (5 bags each month for four months).
   Control (Control and treatments the same as under A)
   Fungicide
   Bacteriocide
   Insecticide

D. White Water — Varzea — Aquatic (beneath 1-3 m of water)
   Control (treatments the same as under A)
   Fungicide
   Bacteriocide
   Insecticide

Thus eighty samples were set out on each of the four sites (A-D) in late August. Once a month for four months, five samples were brought in from each test (80 bags per month) monthly. The bags were placed in a refrigerator at 2° C. until they could be examined under a dissecting scope for the numbers of Arthropods and fungal hyphae present in ten fields (0.5 cm diameter) on the lower side of each leaf. Plans to run bacterial counts on a portion of these leaves failed, although a few counts were taken. The leaves were then dried at 100° C. for 24 hours and weighed to determine actual weight loss on a percentage basis. One gram of the dried leaf material was extracted for total cellulose content while another 1 gram sample was ground and homogenized for the determination of Ca, Cu, Fe, K, Mg, Mn, Na, and Zn using a Techtron

(1) — Fosfato — Dimetil — Dichlorovin 1,50%. Bromophos 0.89%. Pinetras 0.08%. Sulfoxide.

AA-5 atomic absorption spectrophotometer and standard ashing procedures at 525° C. for two hours. The weights of dried leaf material used for cellulose determination were determined by volume so that changes in cellulose content relative to volume could be made. The cellulose content and elemental content of the leaves was determined on dried leaves before placing them in the field and at monthly intervals after they were placed in the field.

The packets which remained in the field were retreated with the same strength of reagents in September and October, although there is little reason to believe that those samples actually placed under water retained these chemicals for a long enough period to have any effect on decomposition. The insecticide may have been somewhat effective because of the oily nature of "Detefon".

By studying the changes over time between leaves on land and in the water, and between leaves on spodosols and oxisols in terms of cellulose, elemental content, Arthropods, percent ash and fungi, it was hoped that a clearer understanding of the dominant factors in decomposition might be recognized, and hopefully provide an explanation for the differences in origin between black and white water.

Associated with the decomposition study were measurements of soil temperature at 3 cm, water temperature at 3 m, oxygen content (Winkler Method) and pH of the water at 3-5 m, pH of the soil at 0-5 and 20-25 cm, pH of rainfall and thrufall and pH and elemental content of litter leachate. The content of IN NH_4OAc extractable Ca, Cu, Fe, K, Mg, Mn, Na and Zn from 0-5 cm and 20-25 cm soil samples was measured using the atomic absorption spectrophotometer for the cations. Total nitrogen was determined by the modified microkjdahl procedure. These data were needed to characterize the soil chemistry of the main terrestrial study sites, and to determine how different these areas actually were in soil chemistry. Some "typical" oxisol and spodosol sites were also analyzed to see how representative the study sites actually were, and to compare soil nutrient content to tree height.

Results and discussion

Litter decomposition — Initial studies

An immediate problem arose with the decomposition study because the harvester ants on the "terra firme" sites quickly carried off all but the leaves treated with insecticide. The insecticide packets had a smaller mesh (1 mm), but not enough to stop the ants since they cut through the heavier, tougher plastic of the 2 mm mesh bags. Ants were also found on leaves submerged under water. The position of each packet also proved to be critical. Those packets which were in contact with the thin humus layer decomposed more rapidly than those placed on top of freshly fallen litter. The leaves used are quite high in Ca, N, P and other elements. It is possible that the ants can detect high nutrient levels in the leaves, and so, selected these dry leaves.

Observations suggest that the litter requires a "softening period" of several weeks or more on the surface before they readily attacked by either fungi or litter animals. This allows time for moistening, bacterial action, and settling into the moist microclimate of the lower litter. Counts of animal feces as an indication of animal activity on "new" and "old" leaves from the forest floor of spodosols showed 0.24 feces/mm^2 on new freshly fallen leaves and 1.09 feces/mm^2 on old leaves which were softened and partly decomposed. Oxisol new litter fall had 0.59 feces/mm^2 while old leaves had 7.26 feces/mm^2 suggesting greater animal activity on oxisol litter compared to spodosol litter. Litter extractions also showed 20.5 animals (aquatic) per 250 cm^3 from "igapó" litter, 150/250 cm^3 from spodosol "terra firme" litter, 28.0/250 cm^3 from "Campina" litter, 90.4/250 cm^3 from oxisol new leaf litter, 261.8/250 cm^3 from oxisol old leaf litter, and only 3.0/250 cm^3 from "Varzea" litter.

Preliminary studies also included fungal counts as the number of fungal hyphae/mm^2. The new leaves from the spodosols averaged 0.647 hyphae/mm^2, while the old leaves averaged 0.981 hyphae/mm^2. The "igapó" had only 0.25 hyphae/mm^2. Some of which could have been on the leaf when it fell into the water. Oxisol new leaf litter had 0.815 hyphae/mm^2 while old litter had 0.923 hyphae/mm^2; suggesting in most cases that older leaves are more readily attacked by fungi.

Another study showed an average pH of leaf surface scrapings from black water litter of 3.45, while the corresponding terrestrial litter showed a pH of 5.10. Spodosol terrestrial litter had a surface pH of 4.85 while the aquatic litter, "Varzea", had 5.40.

The pH of surface leaf scrapings seemed important because of the large number of bacteria cultured from the surface of aquatic litter in some trial dilutions. The black water "igapó" litter with a pH of 3.45 and an oxygen level of from 0.22 to 0 mg/l would defintely favor anaerobic, acidic bacteria while the higher pH range of the "varzea" litter (5.40) would favor a different bacterial flora. The abundance of bacteria in both aquatic litter sites strongly suggests a bacterial dominated decomposition pattern resulting in a high output of organic particulates. Areas of the "varzea" which have white water during high water have been observed to turn to black water as the water goes down and side channels stagnate. Much of the differences between black and white water may be explained by the rate of flow of the water, its sediment load and settling rate, the pH and oxygen content, what types of organisms are the dominant decomposers, and what their final metabolic end product is chemically.

Decomposition of *Caryocar villosum* leaves

Table 1 shows the weight losses as percent of the original dry weight for the leaves used in this study. Although only one species was used, it should give an indication of the general types of organisms which dominate decomposition on spodosol and oxisol terrestrial and aquatic sites.

The control leaves showed rapid weight loss after one month to ants on the spodosol site (Fig. 1). The inundated leaves in the "igapó" (black water) lost about 50% of their dry weight in the first two months, and then leveled off with little additional weight loss. This pattern suggests bacterial decomposition with little or no succession when the bacterial substrate (presumably an organic) is used up, the decomposition slows because few other organisms are able to take over, once the organics are depleted. "Igapó" leaves under water become thinner with little evidence of chewing or breaking. However, the season of heavy larval infestations did not come until the end of the study. Mayfly and midge larvae may be very important at some times of the year. The build-up of Fe, Ca, Mn, P, K and Mg in "igapó" litter with time (Table 2) strongly suggests that this is what occurs. Once the water recedes, the animal and fungal decomposition pattern can return using carbohydrate from softened new litter fall. High N content in the litter would certainly encourage more rapid microbial colonization once the pH is raised and oxygen returns to the system.

Control (untreated) litter on oxisols decomposed in about 2.5 months with heavy litter animal activity and considerable root-leaf contact suggesting some "direct nutrient cycling" (Went and Stark, 1968).

All leaves placed in the white water "varzea" were taken by humans.

When bacteriostat treated leaves were exposed on the spodosol site, ants quickly destroyed these leaves which are rich in nutrients (Fig. 1). The "igapó" litter probably did not retain the bacteriostatic agent, and leaf decomposition closely resembled that of the controls from the "igapó". It is possible that the pH of the "igapó" bottom sediments becomes too low after months of stagnation and flooding so that the active bacteria may be inhibited or slowed by their own acid (pH 3.45). Leaves placed on the oxisol site decomposed in about four months when treated with bacteriostatic agents suggesting that bacteria may be essential in the initial "softening" process on land, and to a lesser extent in later decomposition.

Leaves treated with fungicide were also attractive to the ants and disappeared within one month after exposure. The leaves placed

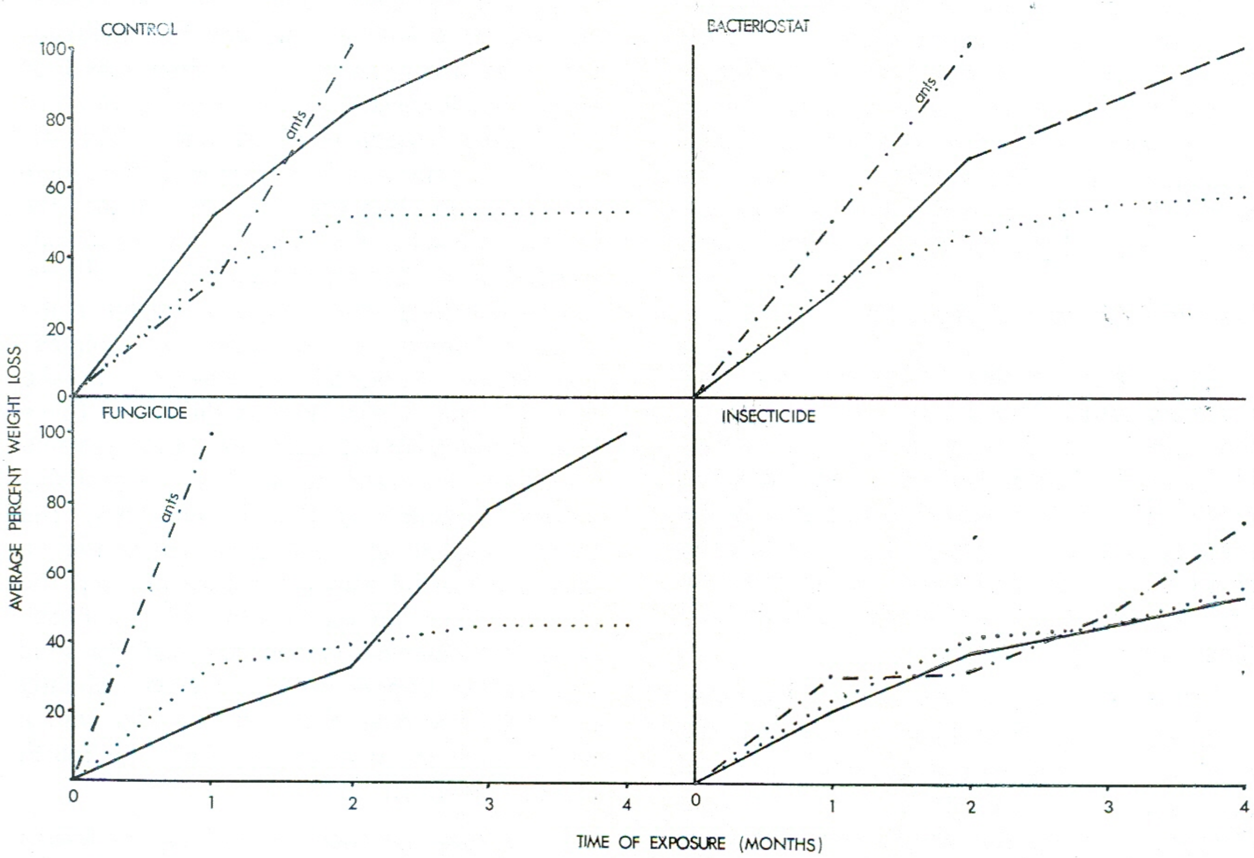

Figure 1. Average percent weight loss with time and treatment for **Caryocar villosum** leaves.
Blackwater Terra Firme —— . —— Blackwater Igapó . . . . Whitewater Terra Firme ————

in the "igapó" decomposed rapidly for the first month and then leveled off in weight loss as did the controls. Fungicide treated leaves in the "igapó" lost slightly less weight (7%) than did the controls suggesting a possible minor role of aquatic fungi in decomposition. The leaves placed on the oxisol site lost nearly all their weight in four months when treated with fungicide (Table 1). The fungicide retarded weight loss by one month suggesting that fungi are relatively important decomposers on the oxisols. The slowed weight loss during the second month is the result of severe drying. Nutrient loss from all treatments on the oxisol site were minimal tending to change little from month to month which is characteristic of a decomposer which "eats" whole parts and does not selectively choose only one substrate within the leaf. There are insufficient data on cellulose content for interpretation.

Figure 1 shows that decomposition on all sites, aquatic and terrestrial, was gradual and nearly identical from month to month for insecticide treated leaves. The leaves did not disappear in four months time and had lost only between 50 and 75% of their original dry weight. The data and observations suggest that litter animals (mites, collembola, insect larvae) are extremely important on the oxisols and nearly as important on the spodosol terrestrial sites. In the water, midges and mayfly larvae were found indicating some importance in the aquatic habitat of aquatic insects. It is too bad that bacterial counts could not have been made to establish the relative importance of aquatic insects and bacteria in decomposition under water. The abundance of bacterial slimes strongly suggests an aquatic decomposition pattern dominated by bacteria; with insects of lesser importance.

The leaves on the black water "terra firme" site lost slightly more weight in the fourth month than did the other leaves. This difference could be attributed to control of fungal eating insects which allowed greater fungal growth. Data to date indicate that fungi are extremely important on the spodosols as decomposers, and particularly mycorrhizal fungi.

Elemental Content of Vegetation

Only one species of leaves, *Caryocar villosum,* was selected for study because of the complexity of using the natural mixed litter. If mixed litter is used in decomposition studies, then it is essential to use exactly the same weight of each type of leaf, including the same weight of petiole versus blade. This handling of litter is extremely difficult and time-consuming.

Unfortunately, the harvester ants were attracted to the control leaf packets on the spodosol site and they completely destroyed these samples after the first month. The rapid disappearance of litter as a result of ants is an indication of the importance of these Arthropods to decomposition. They also destroyed the entire fungicide study within the first month. People removed all of the samples placed in the water of the "varzea" site within the first month. Drying on the "terra firme" sites (spodosol and oxisol) occurred in September because of the dry season. The data cannot be extrapolated to other sites or times of year. Control of fungal or bacterial growth has limited effect if the season is too dry to allow their growth. Full data for four months is available from the black water "igapó" innundated site.

Table 2 shows the μg/g of ten biologically important elements, percent ash, and total cations for the two study sites, three treatments, and innundated versus "terra firme" sites.

In general, Ca decreased slightly with time in the decaying leaves in the "igapó" site under inundation (Fig. 4). It should be remembered that these data are on a dry weight basis and the carbon content was continually changing resulting in periodic comparisons which are not truly comparable. Magnesium showed no significant changes in the leaves with time and remained quite low (245-1800 μg/g. Iron increased in the black water "igapó" leaves regardless of treatment (Fig. 4). The "igapó" site may be considered as an inundated control decomposition test since the chemicals used in the treatments were quickly leached away. The aquatic samples were treated so that they would begin the study in the same condition as the terrestrial samples. Manganese increased considerably in the leaves in the "igapó" site as did iron. These two elements are not readily used by organisms in high concentrations, so they are probably selected against by the decomposers. The least change of all treatments was in the insecticide treated samples suggesting that the chemical used limited all forms of decomposition. This chemical is oily and tends to stick to surfaces. Copper and zinc changed slightly in the leaves over the four months with a slight tendency to increase during the fourth month (Table 2).

The total nitrogen content of the leaves in all surviving tests tended to increase by the second month and then decreased through the fourth month (Fig. 5). The absolute levels of nitrogen probably reflect the nitrogen of the decomposers and their waste products, so that it is impossible to separate completely the protoplasm of the decomposer from that of the substrate. Nitrogen levels were high in the litter ranging from 28,900 to 49,140 μg/g. Litter with these levels of nitrogen are ideal sources of nitrogen needed for plant growth which suggests that direct nutrient cycling can be of great value to growing vegetation. The insecticide treated samples had the lowest levels of nitrogen suggesting that the animal populations normally enrich the litter considerably with their feces. The insecticide treated leaves had levels of nitrogen somewhat lower than that of the controls.

Potassium remained low and stable in the litter samples regardless of treatment (290-1000 μg/g, Table 2).

Phosphorus was moderately high in the litter (2140 to 69 μg/g, Table 2). Surprisingly, the phosphorus levels did not fluctuate much during the four months of the study. The highest levels of phosphorus was in the control and bacteriostat treated leaves, with the least change and lowest levels in the insecticide test (3110 to 5370 $\mu g/g$). Oxisol ("terra firme") and spodosol ("igapó") sites showed the greatest difference in litter phosphorus in the bacteriostat test (Fig. 5). Midge larvae were seen to be quite active on the "igapó"

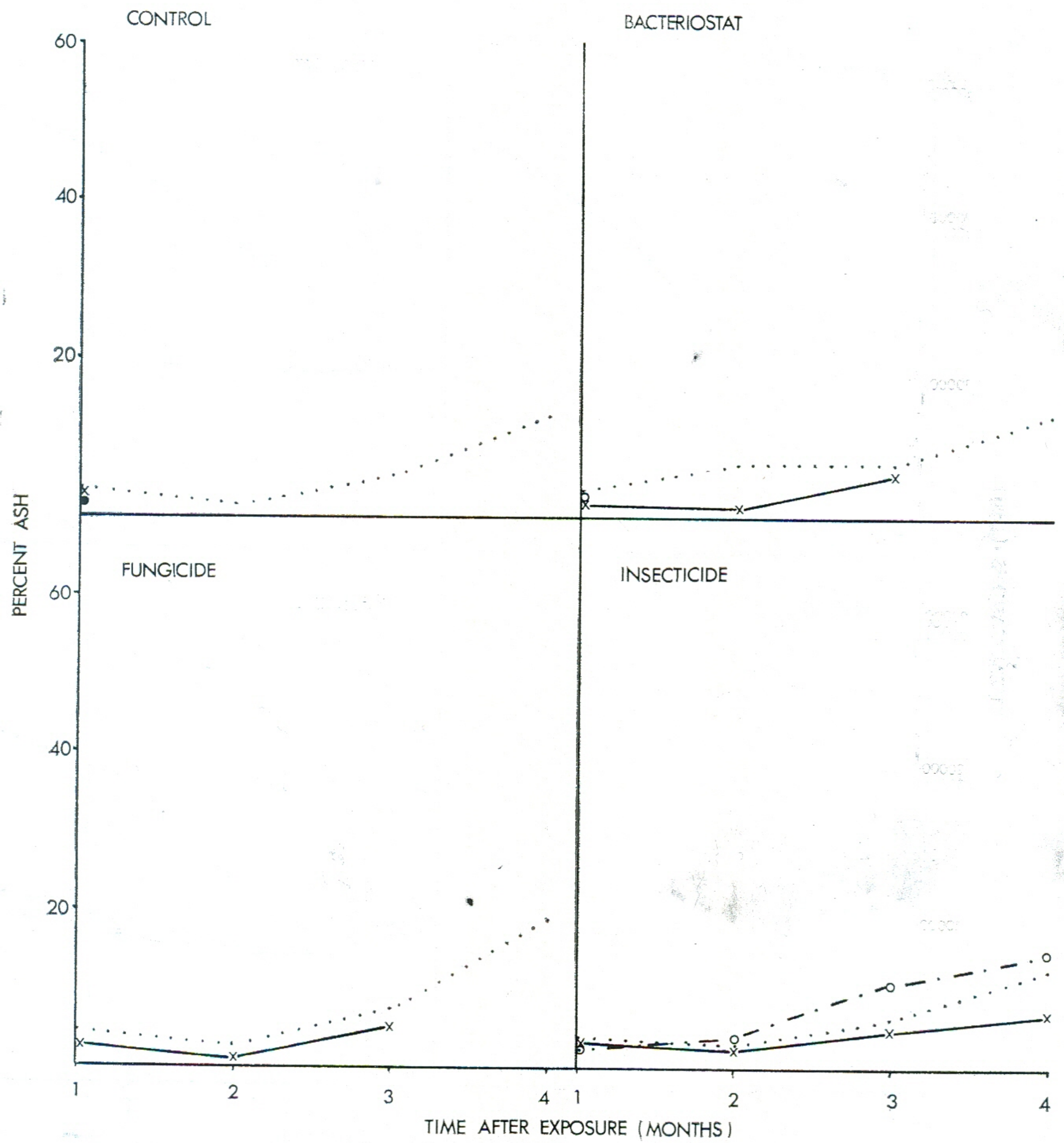

Figure 2. Changes in the average ash content (%) in **Caryocar villosum** leaves with treatment and time.
Spodosol — . — Oxisol x———x Blackwater . . . . Control ●

litter. These organisms may contribute some phosphorus to the decaying leaves. The treatment did not eliminate bacteria which are important in the aquatic decomposition sites and are also high in phosphorus.

Data on the percent ash content (Fg. 2) tended to increase with time for all treatments. The ash content of the controls was 1.8 to 12.62% (Table 2, Fig. 2). The ash content of the bacteriostat tests on the oxisols increased

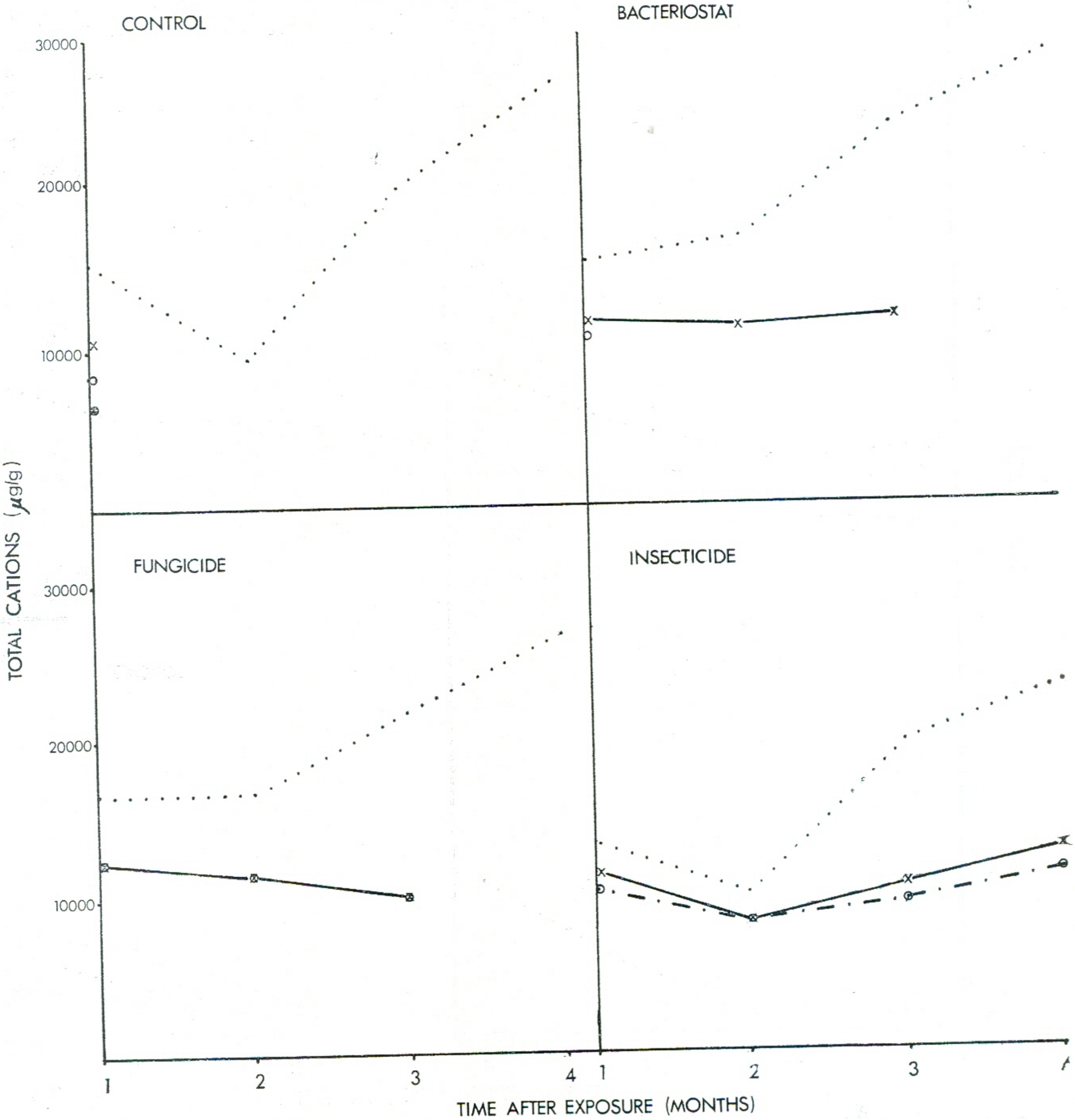

Figure 3. Changes in the total cation content of **Caryocar villosum** leaves by weight, time and by treatment.
Spodosol —— . —— Oxisol ———— Blackwater . . . Initial ● Before Exposure

from 1.6 to 5.88%, while that on the black water "igapó" site changed from 3.54 to 13.24% (Table 2). The ash content of the fungicide treated leaves changed on the oxisol sites from 2.82 to 4.86%, and increased on the black water "igapó" site from 4.04 (decreased to 2.92 in the second month) then increased to 19.04%. It is nearly impossible to interpret these changes in percent ash without corresponding data on cellulose con-

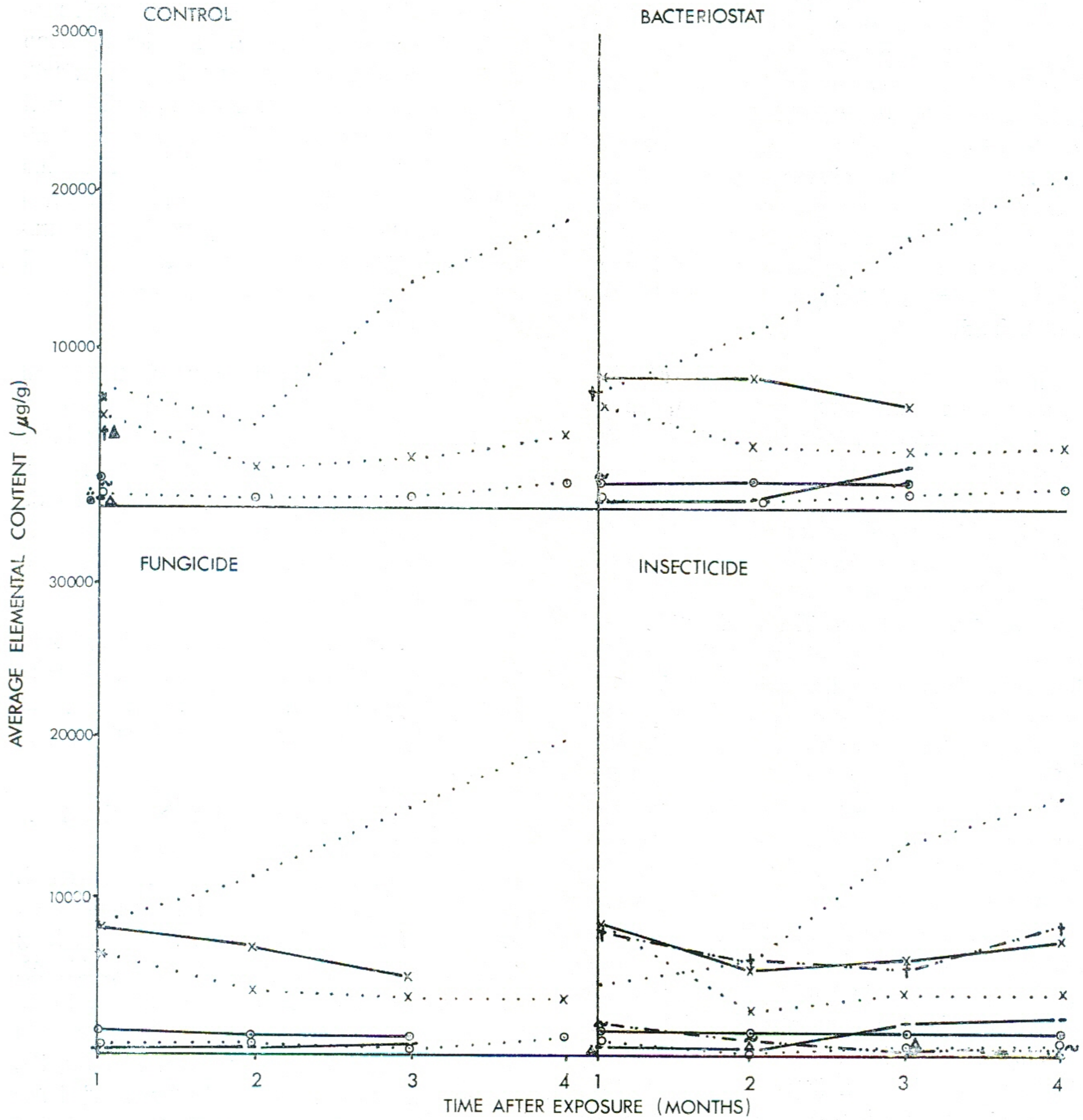

Figure 4. Changes in the average Ca, Mg, and Fe content in **Caryocar villosum** leaves with treatment and time.

Spodosol: Ca †—..—†, Mg ~—..—~, Fe Δ—..—Δ	Oxisol: Ca x———x, Mg o———o, Fe — —— —	Blackwater: Ca x . . . x, Mg o . . . o, Fe	Original: Ca ▲, Mg ●, Fe ∴

tent. The ash content of leaves treated with insecticides changed from 2.70 to 14.94% on the spodosol, from 3.20 (decreased to 2.72 in the second month, then increased to 7.16%, and from 3.92% for the black water "igapó" site to 13.14%.

The initial level of ash in the untreated, unexposed leaves was 3.31 to 3.36% (Table 2), so that many tests showed a slight decline in ash content during the first month. This decrease in ash content is not easy to explain without cellulose data. In nearly all cases, the individual elements increased in concentration on a dry weight basis (μg/g) after one month's exposure. This is probably the result of removal of cellulose and hydrocarbons leaving relatively more of each element behind.

Total cations were calculated in rg/g for the eight cations measured as an indication of the changes brought about by the treatments and exposure time (Table 2). The total cation content varied from 8355 to 28,772 μg/g. The controls which were untreated had 8,418 to 10,876 μg/g while the unexposed and untreated leaves had 6628 to 6723 μg/g of total cations at the start of the tests. The total cation content increased most drastically in the "igapó" sites regardless of treatment (Fig. 3). The total cations changed little on samples placed on oxisols and those on terra firme spodosols. Decomposition on the "igapó" sites appears to be selective removing some materials and not others as is the case with bacterial and some types of fungal decay where a specific substrate is required. When the insects were not controlled on terra firme sites, the decomposition appeared to be less selective with the disappearance of whole leaf segments and without a selective concentration of total of specific cations. The oxisol sites appear to be strongly dependent on litter animals for decomposition with a lesser dependence of spodosol litter on animal decomposers.

Litter from the bottom of black water streams had high ash contents (28.26 to 28.48%) and low total cations (2544 to 2753 μg/g, Table 2). Those data suggest that some element not measured in the eight cations is present in great quantities in the black water areas. Silicon is one element which may be very high in the decomposing "igapó" litter, but was not measured here. Similar discrepancies exist between other sites where total cations and percent ash were measured, probably for the same reason. In addition, these plants were digested by dry ashing at 525° C. which means that elements such as silica will not go into solution, while others such as nitrogen will volatize during ashing. For this reason, total nitrogen was determined from a wet digestion of 0.1 g samples by the microkjeldahl procedure. Percent ash and total cations cannot be expected to agree under these circumstances.

Other "igapó" sites showed 10,394 to 10,562 μg/g of total cations, and 16.39 to 17.53% ash (Table 2). Campina Creek litter (inundated) was low in both percent ash (7.58-7.62%) and total cations (1434-1457 μg/g) which is a direct reflection of the low elemental content of "campina" vegetation and soil in general.

Litter from oxisol soils showed 9,264 to 9,402 μg/g total cations and 9.13 to 9.18% ash, a reflection of a slightly richer site, but one which is poor from severe leaching (Table 2).

"Varzea" litter had very high total cations (13,134 to 13,786 μg/g) and high percent ash (68.23 to 68.7%) indicating a nutrient rich river bottom litter capable of releasing large amounts of cations and anions, and enriching the soil when the waters subsided (Table 2). The "varzea" litter was noticeably low in nitrogen (5,740 μg/g) compared to 14,000 μg/g for "igapó" litter. High levels of Mg, Cu, Fe, K and Zn were found in the "varzea" litter (inundated). It is interesting that the soil also showed relatively high levels of Mn, Mg, K, and Zn, but low levels of Fe. The balance of Fe in the decomposing litter could well influence what kinds of microorganisms can and will

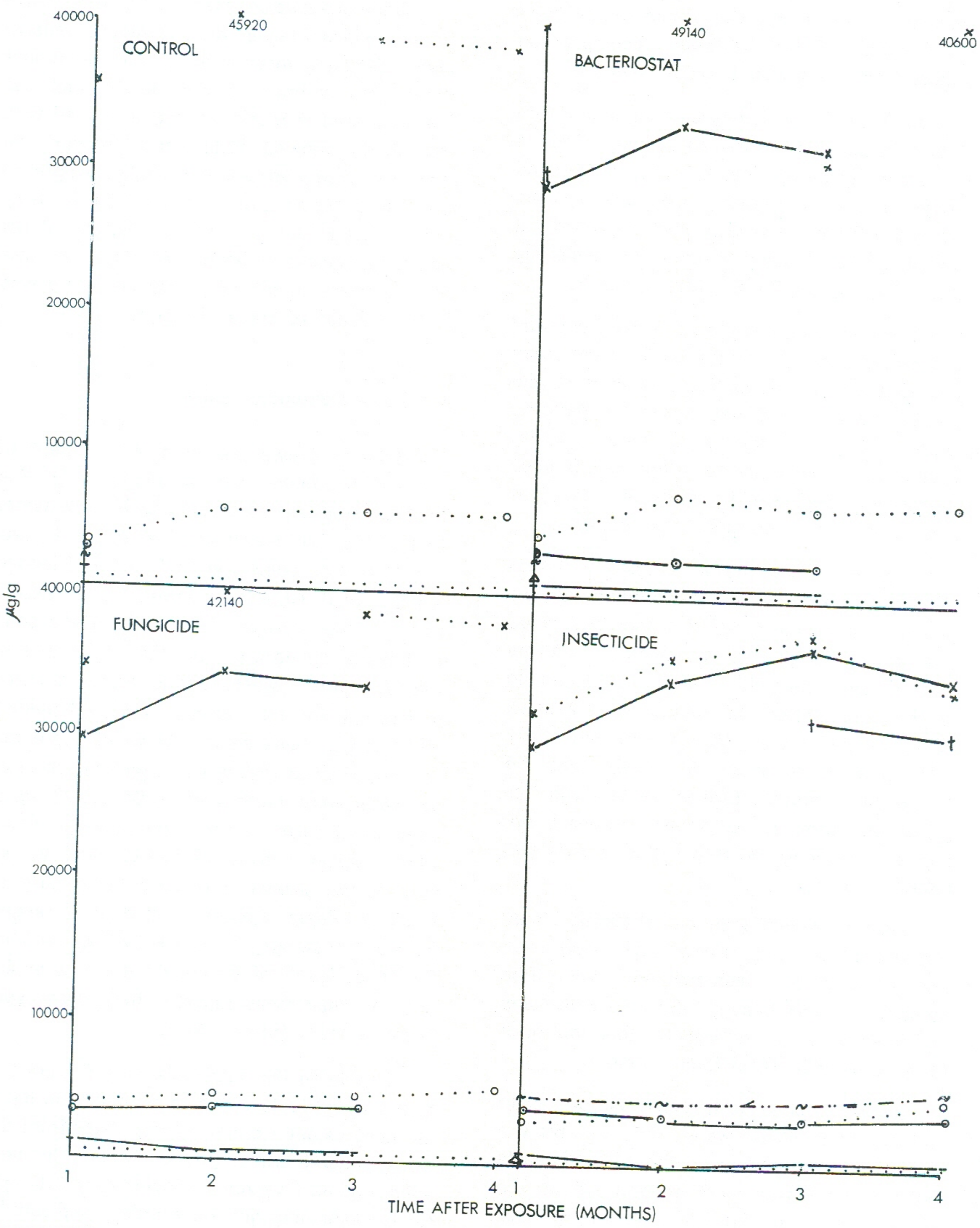

Figure 5. Changes in the N, P, and K content of **Caryocar villosum** leaves with treatment and time.

Spodosol		Oxisol		Blackwater	
N	†———†	N	x———x	N	x . . . x
P	⌐———⌐	P	o———o	P	o . . . o
K	Δ	K	— — —	K	. . . . .

decompose the litter. Conditions in the "varzea" would favor bacterial decomposition where iron is a possible active agent.

In general, the levels of elements in the "terra firme" litter agree with those from a former study on spodosols (Stark, 1971). The *Caryocar* leaves represent only one species while the litter analyzed in 1971 represents a conglomerate of many species with generally lower Cu, Fe, Mn, Zn, Ca, Mg, N, and P.

The elemental analyses of litter from land and water from white and black water areas has shown some distinctive difference in elemental content and decomposition pattern. Unfortunately, the data on bacterial activity in these sites could not be determined. Studies of microbial ATP would provide the key information needed to interpret these data.

Figs. 6-10 show the appearance of leaves of *Caryocar* after different treatments and exposure time in the field. Unfortunately, there are no photographs of the controls. Leaves treated with fungicide show considerable fragmentation after four months in the black water "igapó" but the leaves were noticeably thin. There is no reason to believe that the treatment persisted. Leaves treated with fungicide on "terra firme" (oxisol) showed evidence of chewing and fragmentation after two months (Fig. 6).

Leaves treated with bacteriostatic agent and placed on "terra firme" (spodosol) were nearly completely decomposed after three months and were heavily infiltrated with roots and fungi (Fig. 7). It is probable that control of bacteria allowed rapid fungal growth.

Leaves treated with bacteriostatic agent and placed in black water did not show a strong effect of the chemical because of leaching, but the leaves were fragmented on the edges (Figs. 7, 8). After four months in black water, the leaves were heavily fragmented. Bacteriostat treated leaves on oxisol "terra firme" showed progressive fragmentation, insect damage, and root actitivy (Fig. 8).

When insecticide was used, the "terra firme" spodosol leaves did not show extensive insect damage. Insects were not prominent during the months of this study, and the leaves placed in black water and treated with insecticide showed little decomposition and almost no insect damage (Fig. 9). Leaves placed on oxisol "terra firme" were heavily fragmented after four month's exposure. Roots and fungi appear to have been important during the fourth month (Fig. 10), but there was little evidence of insect damage.

Elemental Content of Soils

Table 3 shows the elemental content of various spodosols and oxisols in $\mu g/g$. The first ten soils are associated with black water rivers and are extremely low in Ca, K, Mg, Mn, N and Zn compared to "varzea" (flooded white areas) sites or oxisols. Some exceptions are the nitrogen levels of surface soils on lowand spodosols, and the Mg levels of the "Campina" forest. Areas which are rich in calcium are the "varzea inundated muck", and "varzea" bank sediments which were not recently flooded (Table 3). In general, the oxisol soils were quite low in Ca (10-26 $\mu g/g$) even when earth worms were present. Black water "igapó" (drowned forest) had 26 μg ca/g at the surface, and only 15 μg ca/g at 20-25 cm depth. Spodosols in general ranged from 9.5 to 26 $\mu g/g$ for IN NH_4OAC extractable Ca. These levels of Ca are the same to slightly lower than those reported from Brazil spodosols in 1971 (Stark, 1971).

Copper in the spodosols ranged from 0.8 to 2.5 $\mu g/g$ (Table 3) which is about the same as those values from an earlier study from the same general areas (Stark, 1971). The best soils studied ("varzea") showed only 3.0 $\mu g/g$ for Cu indicating generally widespread low levels for this element.

Extractable iron content ranged from 0.8 to 22.5 $\mu g/g$ for the spodosols, with not over

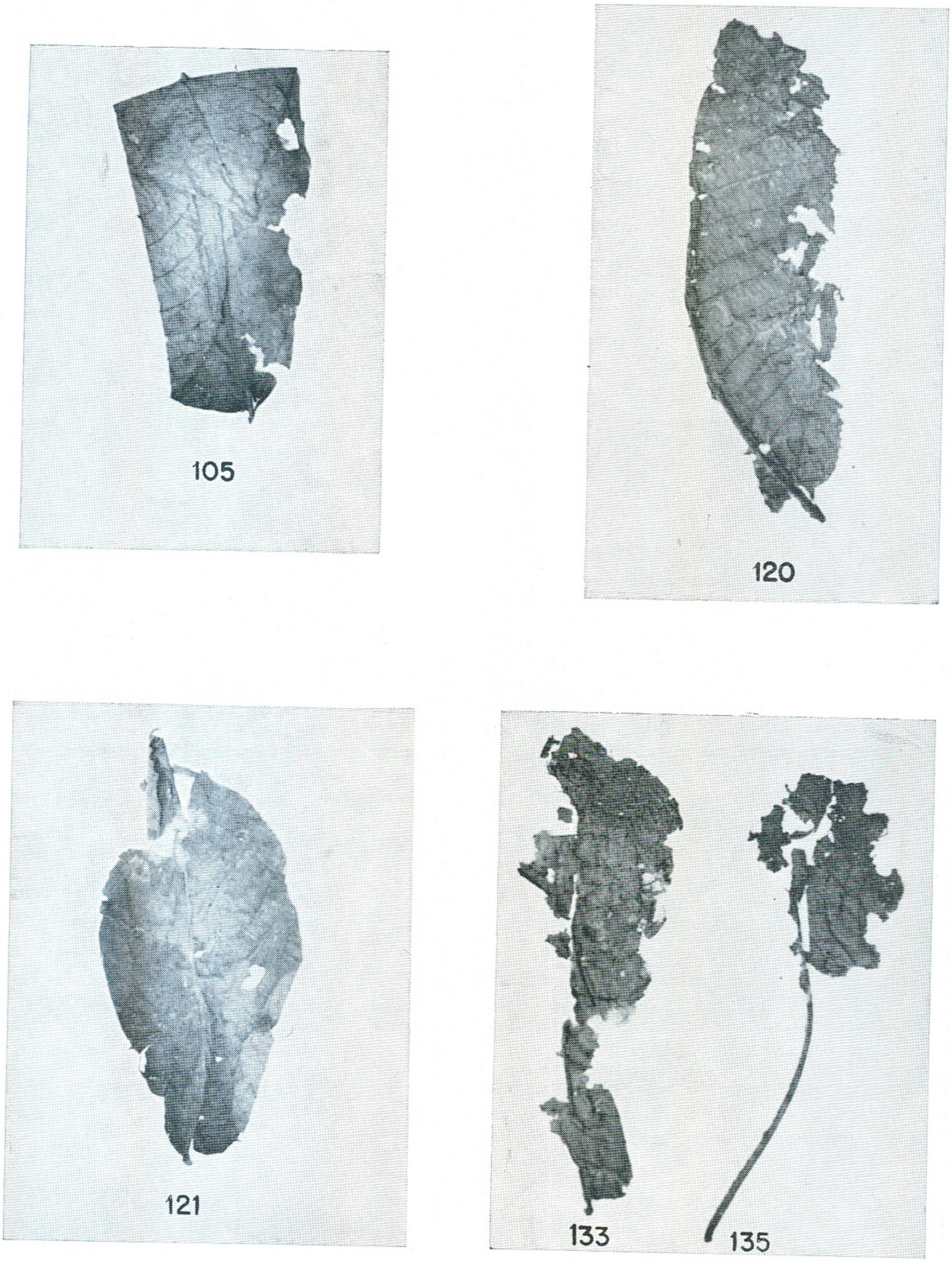

Fig. 6. N°s. 105, 120. Leaves of **Caryocar** treated with fungicide and placed in black water "igapó" for one and four months respectively. N°s. 121, 133-135. Leaves treated similarly but placed on oxisol "terra firme" for one and three months respectively.

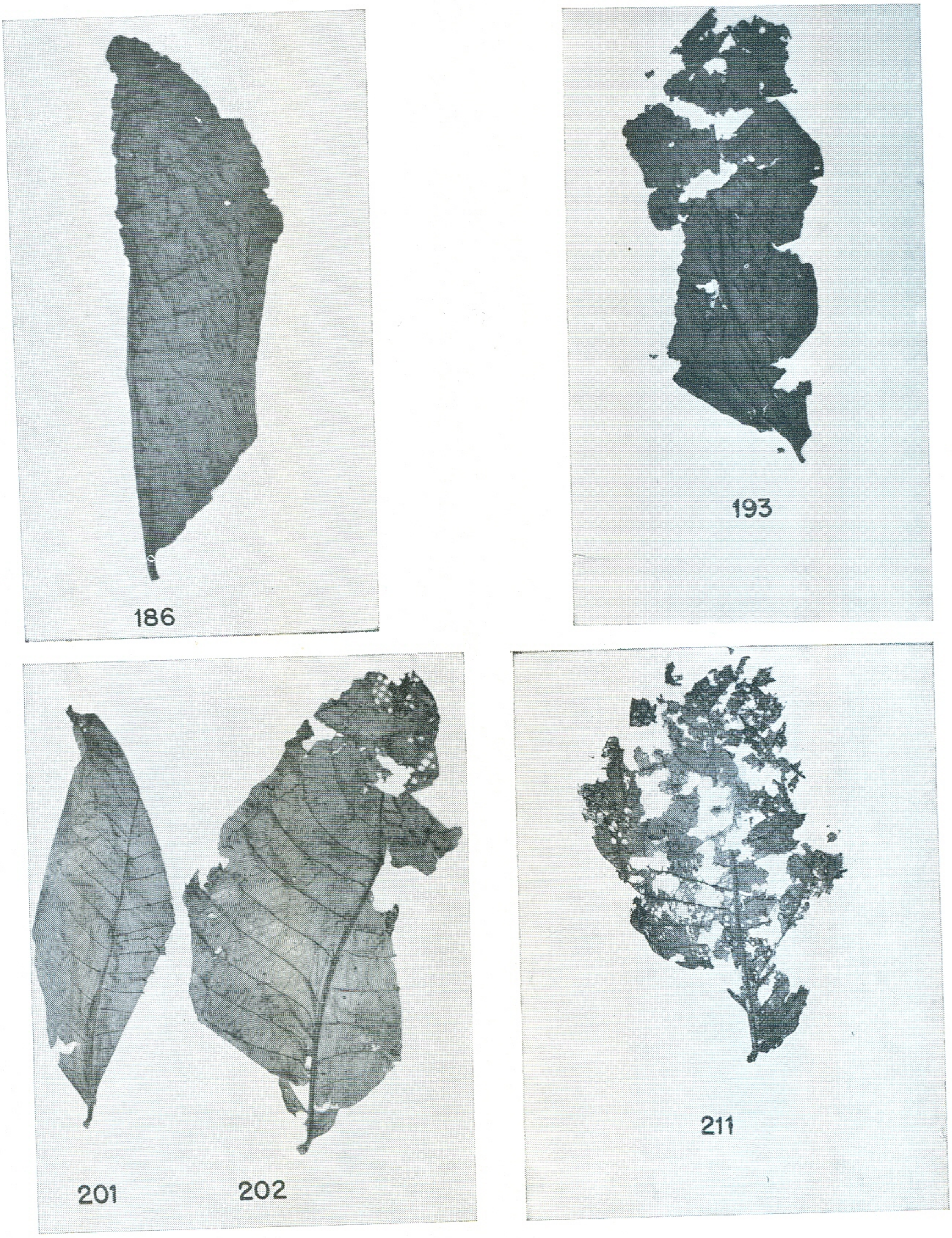

Fig. 7. N°s. 186, 193. Leaves of **Caryocar villosum** treated with bacteriostat agent and left in "igapó" (blackwater), for one and three months, respectively. N°s. 201, 202, 211. Leaves treated similarly but left on oxisol "terra firme" for one and three months respectively.

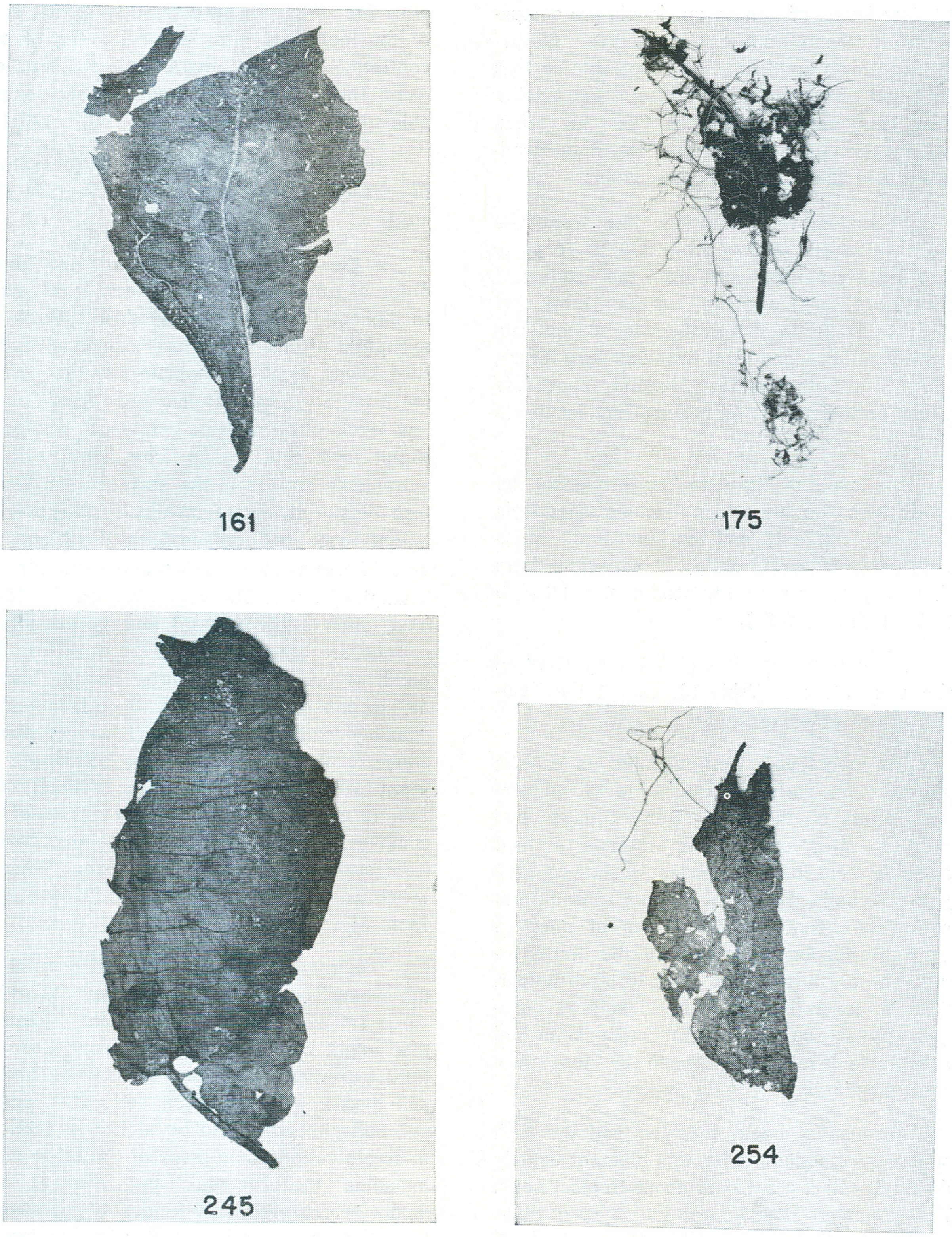

Fig. 8. N°s. 161, 175. Leaves of **Caryocar villosum** treated with a bacteriostatic agent and left on spodosol "terra firme" for one and three months respectively. N°s. 245, 254 leaves treated with insecticide and left on spodosol "terra firme" for one and three months respectively.

31 μg/g from the best "varzea" sites (Table 3). The levels of iron on spodosols are comparable to those from earlier studies. Extractable iron on spodosols is comparable to that obtained from earlier studies. Extractable iron is generally sufficient from all areas studied except the "campina" forest on sandstone and the black sand spodosols.

Potassium was generally low from the spodosol areas ranging from 5.5 to 74 μg/g. The highest values were from the "campina" forest (74 μg/g) and the "varzea" sites (85 μg/g, Table 3). In 1971, values for K from this general area ranged from 12 to 320 μg/g (Stark, 1971). In both studies, lowland spodosols which periodically flood had the highest levels of K.

The levels of Mg were low throughout the study with the lowest on lowland spodosols (2.9 μg/g, Table 3), and the highest on "campina" spodosols (23 μg/g). Magnesium from these soil types were reported at 2 to 39 μg/g in 1971 (Stark, 1971).

Manganese was low (0.3-5.5 μg/g) in all the soils studied (Table 3), except the "varzea" sites (144 μg/g).

Nitrogen levels were variable as can be expected for surface soils (Table 3). Inundadated sites on the black water "igapó" had only 252 μg/g for nitrogen whereas surface samples from lowland spodosols showed 3164 μgN/g of soil. The oxisol surface soils did not show significantly higher levels of nitrogen over the spodosols, except for the "terra firme" primary forest with trees to 50 m height. Oxisols generally had higher levels of nitrogen at 20-25 cm depth, but most sites had acceptable levels of nitrogen by temperate zone standards.

Because of heavy leaching and the high solubility of sodium salts, this element usually does not tell a great deal about tropical soils. The inundated "igapó" site had 7 μg/g while the inundated varzea soils had 28-31 μgNa/g of soil, and the dry site (not recently flooded) "varzea" sites had 37 μg/g for this element (Table 3). Campina Creek mud had the highest Na (41.3 μg/g), except for lowland spodosol sites (62 μg/g). These data suggest that some of the inundated sites are collecting or concentrating Na while others are losing this element. The levels of Na found here are comparable to those reported earlier (Stark, 1971).

Zinc was low (0.5 to 1.1 μg/g, Table 3) on nearly all soils except the "varzea" (2.3 μg/g).

If the surface soils are arranged in the order of total extractable cations from lowest to highest (Table 4), the spodosols (with the exception of one agricultural oxisol) all fall in the lower total extractable cation range (44.8-130.6 μg/g. These are exceptionally low levels of extractable cations. A coniferous forest soil will range from 2975 μg/g of extractable cations in the surface soil. Where tree height data are available, the average height tends to increase with the higher levels of extractable cations, except for the "campina" sites. The vegetation on the "campina" sites is low (8-10 m), and the extractable cations are also low (80.2-130.6 μg/g). The depth of undecomposed litter in the "campina" is generally low (under 2 cm), indicating possibly lower production and greater dependence on the soil nutrients, or less direct nutrient cycling from organic litter to living roots. This is consistent with the dry nature of the campina. The highest total extractable cations from surface soil come from the "varzea" which was not flooded in August (2290.9 μg/g, Table 3).

The total extractable cation content of the subsurface soils is generally low (35.3-128.5 μg/g, Table 3). Where tree height is known, the height correlates more closely with the total extractable cations from the subsurface soil than from the surface soil. The "campina" subsoils appear to be higher in total extractable cations than many of the other sites, including the "varzea", but average tree height is extremely low (under 10 m) suggesting that some other factor is limiting to growth, possibly the anions NO_2^- or PO_4^-. Nitrate is low for soil 2B on sandstone (392-630 μg/g, Table 3). Organic litter and tree height

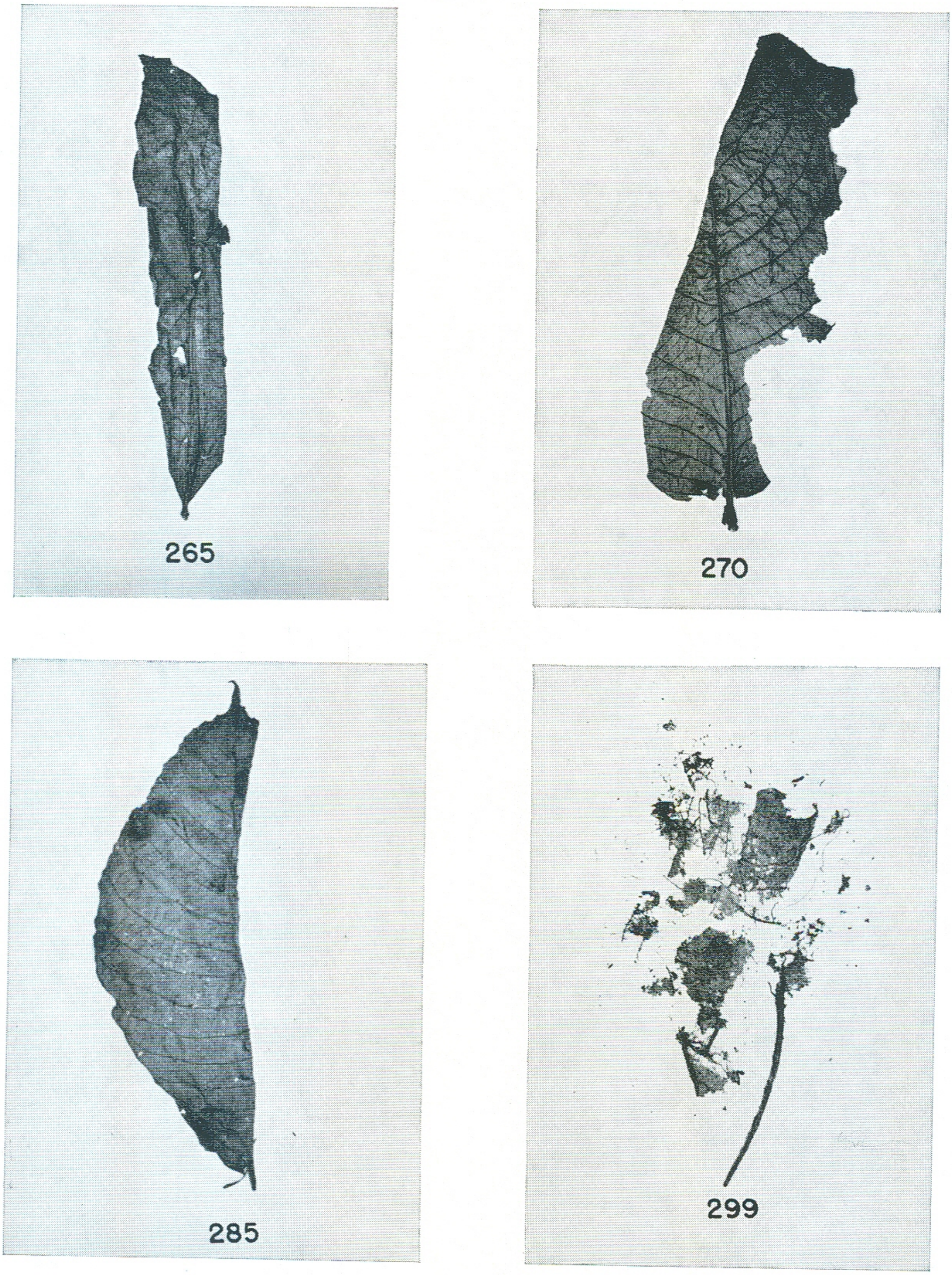

Fig. 9. N°s. 265, 270. Leaves of **Caryocar villosum** treated with insecticide and left in the black water of the "igapó" for one and two months respectively. N°s. 285, 299 leaves treated similarly, but exposed to oxisol "terra firme" for one and four months respectively.

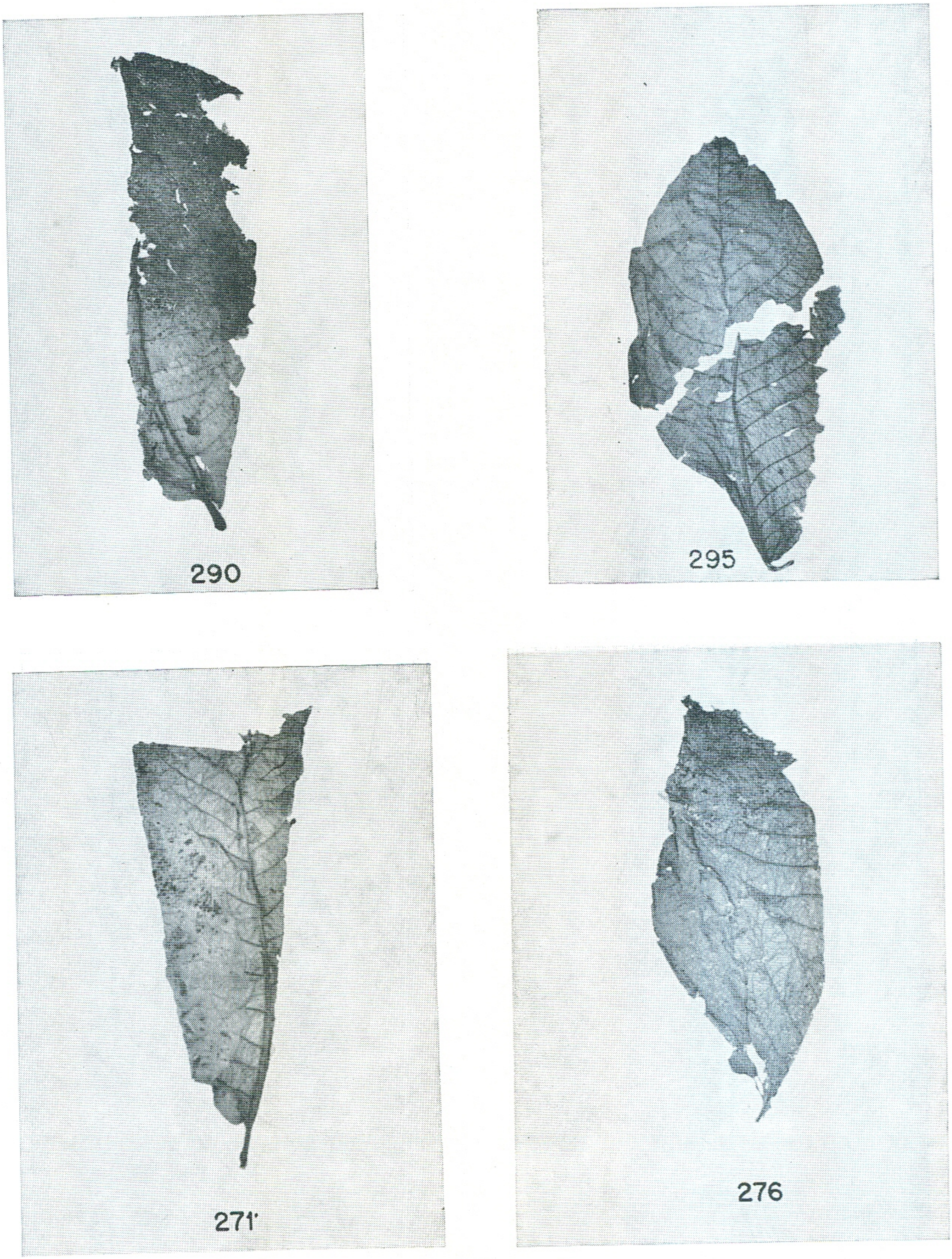

Fig. 10. N°s. 290, 295. Leaves of **Caryocar villosum** treated with insecticide and placed on oxisol "terra firme" for two and three months respectively. N°s. 271, 276. Leaves treated similarly and left in black water "igapó" for three and four months.

do not appear to be closely related from these limited data, but more information is definitely needed. For surface soils, the deeper litter tends to be on the poorest soils suggesting a strong dependence on litter. These soils have relatively small forests of 20-30 m high.

The pH of surface spodosols averaged 3.65 with 3.98 at 20-25 cm while the pH of the "igapó" was 5.45 and 5.35 respectively, and the oxisol sites were 3.84 and 4.28 respectively. The "varzea" pH was 6.58. Soils with earth worms (3.8) were generally in the middle range of extractable cations for the surface and high in extractable cations in the subsoil.

Although this study was not able to sample adequately to fully describe the relations of vegetation to soils and nutrient cycling, the data do indicate some interesting trends. Future studies should include tree height, biomass per hectare, extractable cations, anions, organic litter depth, root mat (depth, and location), and studies of direct and indirect nutrient cycling to fully describe nutrient cycling differences from spodosols and oxisols.

The spodosol terra firme litter appears to be decomposed mainly by fungi (possibly mycorrhizal fungi) and litter animals. This litter also requires a softening period before rapid decay begins. Once the leaves are properly softened, decay is rapid and complete within a month or so. Ants are extremely important decomposers on spodosols.

The richest soils are the "varzea" soils as is well known. There is some relationship between tree height and fertility, but litter depth complicates this relationship.

Caryocar leaves changed in elemental content and percent ash as it decays tending to increase in concentration with time. These leaves are rich in N, P, and Ca. "Varzea" litter is one of the richest types of natural litter types in Amazonia, except in nitrogen. The "Campina" litter is the poorest of forest litters in nutrient content.

Conclusions

This brief study cannot hope to have amassed enough data to explain all of the differences in nutrient cycling on black and white water soils. It has been shown that a factor of prime importance is the rate of decomposition and the dominant decomposer groups and their waste products. Studies on the nature of the leaching solution which falls through the forest canopy and contacts the litter on the forest floor were cancelled because of time. Such studies should be continued to fully explain nutrient cycling since it is probably the pH and chemistry of the leaves and their microenvironments which finally determines which organisms will dominate the decomposition of litter, and in what sequence. Nutrient cycling appears to be strongly related to type and rate of decomposition, and less to soil types, although white water depends on a clay to provide the sediment load. Decomposition occurs in an acid, anaerobic environment which after a time may stagnate further decay. The decay end products are particulate organics which give the water its color and these can form under water or either oxisols or spodosols if the aeration, pH and currents are suitable. The pH of the water coming from the land may also be important to determining the dominant decomposers. The build-up of cations in this litter suggests selective decomposition by bacteria.

Oxisol terrestrial sites appear to be dominated by litter animals which require a period of softening of the leaves by moisture and bacteria before they become abundant. Mycorrhizal fungi and certainly free-living fungi are also important decomposers on oxisols. The nutrient loss pattern suggests decomposers that "eat" chunks of leaf rather than selective decay of one fraction of the leaf. This "eating" reduces all elements proportionately.

Table 1. Average weight loss as percent of original dry weight for **Caryocar villosum** leaves under different treatments overtime, Brazil blackwater and whitewater streams and spodosol and oxisol terra firme sites.

Site and Site and Treatment	Packet Number	Time Exposed Months	Average Weight Loss %	Average % Cellulose	Roots	Av. No. Litter Animals	Fungi
CONTROLS							
Blackwater Tf[1]	1-5	1	32.41	17.75		22	Light
	6-20	1	100.00 (ants)				
Blackwater Ig.[1]	21-25	1	35.23		None	2	V. light
	26-30	2	50.67	18.14	None	14	V. light
	31-35	3	52.60	22.60	None	2 midge[2]	V. light
				17.23		larvae	
	36-40	4	53.40		None	9	V. light
Whitewater Tf	41-45	1	52.84	18.16	Light	10	Light
	46-50	2	83.99				
	51-60	3	100.00				
Whitewater varz[1]	56-80	1	(stolen)				
FUNGICIDE							
Blackwater Tf	81-100	1	100.00 (ants)				
Blackwater Ig.	101-105	1	34.04		None	3	V. light
	106-110	2	39.99		None	13 (midge)	None
	111-115	3	44.66		None	7 (midge)	V. light
	116-120	4	45.80		None	5 (midge)	V. light
Whitewater Tf	121-125	1	19.79		None to	3	V. light
					medium		
	126-130	2	33.11		Medium	3	Medium
	131-135	3	78.52		Medium	Incomplete	V. heavy
	136-140	4	100.00				
Whitewater varz	140-160	1	(stolen)				
BACTERIOSTAT							
Blackwater Tf	161-165	1	49.87		Medium	18	Light
	166-180	2	100.00 (ants)		Heavy		
Blackwater Ig.	181-185	1	31.86		None	1	V. light
	186-190	2	45.98		None	21	V. light
	191-195	3	54.07		None	10 (midge)	V. light
	196-200	4	57.70		None	8 (midge)	V. light
Whitewater Tf	201-205	1	29.08		None	12	Light
	206-210	2	68.86		Light	4	Light
	211-215	3	51.22		Medium	4	Light
	216-220	4	100.00				
Whitewater varz	220-240	1	(stolen)				
INSECTICIDE							
Blackwater Tf	241-245	1	31.01		Light	6	Medium
	246-250	2	32.50		Medium	0	Medium
	251-255	3	48.83		Light	6	Medium
	256-260	4	75.64		Light	Incomplete	V. light
Blackwater Ig.	261-265	1	24.22		None	0	
	266-270	2	42.22		None	0	V. light
	271-275	3	45.74		None	2 (midge)	V. light
	276-280	4	56.92		None	4 (midge)	V. light
Whitewater Tf	281-285	1	21.19		None	0	V. light
	286-290	2	37.02		Light	0	Light
	291-295	3	45.71		Medium	14	Light
	296-300	4	53.20		Medium	10	V. heavy
Whitewater Varz	301-320	1	(stolen)				

(1) — Blackwater Tf = spodosol, not flooded, whitewater Tf = oxisol, not flooded.
Blackwater Ig. = spodosol, flooded, whitewater varz. = oxisol, periodic flooding.
(2) — Midges and mayfly larvae are combined for aquatic counts.

Table 2. Average elemental content, total cations, and percent ash of **Caryocar villosum** leaves after different lengths of exposure on terrestrial and aquatic sites associated with oxisols and spodosols.

μ g/g

Treatment and Location	Length of Exposure Months	Ca	Cu	Fe	K	Mg	Mn	N	Na	P	Zn	% Ash	Total Cations
Controls													
Spodosol	1	5000	76.0	310	790	1400	75	28,980	480.0	2140	287.0	1.80	8,418
Oxisol	1	7000	61.0	690	1000	1600	108	30,800	360.0	3220	57.0	3.22	10,876
Blackwater	1	5900	35.0	7500	560	600	393	35,560	350.0	3840	71.2	3.54	15,409
	2	2500	34.0	5000	430	400	1000	45,920	225.0	5370	46.0	1.82	9,635
	3	3100	27.0	14,000	370	790	2000	38,780	107.0	5450	34.0	5.68	20,428
	4	4400	38.0	18,000	650	1250	2200	37,100	260.0	5600	60.0	12.62	26,858
Bacteriostat													
Spodosol	1	7300	35.0	250	910	1860	106	29,120	250.0	3160	62.0	2.10	10,773
Oxisol	1	8200	42.0	340	930	1670	142	28,900	227.0	2930	51.0	1.60	11,602
	2	8000	47.5	505	720	1620	110	33,200	360.0	2740	42.0	1.84	11,405
	3	6000	59.5	2800	810	1580	108	31,920	402.0	3280	71.0	5.88	11,831
Blackwater	1	6500	38.0	7400	460	550	280	35,000	195.0	4300	59.4	3.54	15,482
	2	4000	20.0	11,000	690	540	125	49,140	430.0	7200	85.0	6.50	16,890
	3	3600	29.0	17,000	470	820	200	30,940	120.0	6400	39.0	6.64	24,078
	4	3800	41.0	21,000	590	1080	2000	40,600	200.0	6900	61.0	13.24	28,772
Fungicide													
Spodosol	1												
Destroyed by Antes													
Fungicide													
Oxisol	1	8000	23.0	182	950	1600	1100	29,960	155.0	2740	290.0	2.82	12,305
	2	7000	36.0	380	590	1450	1500	34,440	145.0	3780	350.0	1.54	11,451
	3	5000	95.0	780	574	1070	1800	33,460	275.0	3960	495.0	4.86	10,089
Blackwater	1	6300	32.0	8300	440	700	560	34,720	220.0	3960	96.0	4.04	16,648
	2	4000	28.0	11,200	545	620	165	42,140	280.0	4770	50.0	2.92	16,888
	3	3600	23.0	16,000	490	800	820	38,500	135.0	4630	39.0	7.28	21,907
	4	3500	53.5	20,000	670	1100	830	34,580	235.0	5150	186.0	19.04	26,575
Insecticide													
Spodosol	1	7800	43.0	226	800	1600	96	29,800	230.0	4630	89.0	2.70	10,884
	2	5600	45.5	610	400	1500	86		66.0	4570	47.0	3.90	8,355
	3	5800	110.0	1000	860	890	90	31,360	610.0	4630	56.0	10.80	9,416

Table 2. (continued)

μ g/g

Treatment and Location	Length of Exposure Months	Ca	Cu	Fe	K	Mg	Mn	N	Na	P	Zn	% Ash	Total Cations
	4	8300	49.5	690	810	980	105	30,660	380.0	5370	41.0	14.94	11,356
Oxisol	1	8200	51.0	390	810	1600	128	29,260	110.0	3960	55.0	3.20	11,344
	2	5600	45.5	610	410	1500	80	34,020	65.0	3280	48.0	2.72	8,359
	3	6200	69.0	2000	490	1320	116	36,400	246.0	3390	66.0	5.30	10,507
	4	7600	88.0	2500	510	1700	130	34,160	190.0	3670	76.0	7.16	12,794
Blackwater	1	8000	45.0	4200	220	510	197	31,640	120.0	3110	45.0	3.92	13,337
	2	3000	59.0	6000	290	400	100	35,560	151.0	3330	60.0	3.08	10,060
	3	4000	81.0	13,700	310	800	740	37,240	86.0	3500	51.0	6.96	19,768
	4	4000	46.5	16,500	490	1000	800	33,460	148.0	4850	47.4	13.14	23,032
Initial Before Exposure	1	5350	11.0	110	675	245	105	20,580	117.5	3750	15.0	3.36	6,628
	2	5450	10.0	105	675	245	105		117.5	3750	15.0	3.31	6,723
Terra Firme Litter Spodosol Manacaparu	1	1500	12.0	120	435	475	65	20,300	850.0	2685	21.5	4.80	3,479
	2	1750	13.0	120	435	500	65		850.0	2685	20.5	4.52	3,754
Blackwater Litter		1100	11.8	450	325	260	45	15,960	340.0	1440	12.2	28.48	2,544
		1300	11.5	425	325	300	44		335.0	1440	12.2	28.26	2,753
Blackwater Litter		8700	12.0	730	255	510	115	14,000	59.0	1030	13.2	17.53	10,394
		8800	12.3	730	255	575	116	14,000	60.0	1030	13.5	16.38	10,562
Igapó Litter													
Litter, bottom of Campina Creek (Black Water)		500	7.8	405	228	200	20	9,100	66.0	500	7.0	7.58	1,434
		500	8.5	410	230	205	20		76.0	500	7.4	7.62	1,457
Oxisol Litter		7750	11.8	725	155	450	110	12,880	48.5	3750	13.0	9.13	9,264
		7900	11.8	700	153	470	108		45.5	3750	13.0	9.18	9,402
Punta Negravic. Site 1		2000	8.5	3850	340	950	92	14,560	470.0	890	9.1	23.60	7,720
		1900	8.5	3850	340	925	90		470.0	890	9.0	22.11	7,593
Varzea litter		5500	21.5	2050	1900	3525	470	5,740	255.0	2150	64.0	68.23	13,786
		5250	21.0	1975	1750	3375	465		235.0	2150	63.0	68.70	13,134

Table 3. Levels of IN NH_4OAc extractable and total cations found in spodosols and oxisols from Brazil, and total nitrogen. $\mu g/g$

Site	Depth cm	Ca	Cu	Fe	K	Mg	Mn	N	Na	Zn
Blackwater										
Igapó	0-5	26	0.9	3.8	10.0	3.8	0.7	252	7.0	1.0
(inundated)		26	0.9	3.8	10.0	3.9	0.7		7.0	1.0
	20-25	15	1.0	2.5	8.5	3.2	0.4	210	7.0	0.8
		15	1.0	2.5	9.0	3.1	0.4		8.4	0.8
Lowland										
Spodosol	0-5	12.5	1.5	22.5	32.5	9.2	0.8	3164	26.0	0.7
trees		11.0	1.5	22.5	31.0	9.2	0.8		25.2	0.8
25 m	20-25	11.5	1.5	5.5	40.0	5.0	0.2	1372	62.0	0.5
		11.5	1.5	5.8	41.0	5.0	0.2		62.0	0.5
Lowland										
Spodosol	0-5	10.0	1.5	12.8	23.5	6.7	0.5	2785	18.5	0.7
trees		10.0	1.4	12.8	23.5	6.7	0.5		17.0	0.6
30 m	20-25	10.0	1.3	6.3	15.0	3.0	0.3	980	13.2	0.5
		10.0	1.3	6.5	15.0	2.9	0.3		13.5	0.5
Campina-like										
soil on	0-5	25.0	2.5	1.1	30.0	12.5	0.6	630	13.0	1.0
sand stone		20.0	2.3	1.1	25.0	12.0	0.5		13.0	0.8
trees 10 m										
(Stream areas)	20-25	10.0	2.3	0.8	10.0	4.3	0.1	392	11.0	0.8
		10.0	2.3	0.9	10.0	4.5	0.1		11.5	0.8
Terra firme										
Spodosol	0-5	10.0	2.5	6.5	14.0	5.2	0.2	1316	14.0	0.8
trees		10.0	2.5	6.5	14.0	5.2	0.2		14.0	0.8
30 m	20-25	10.0	2.1	6.0	5.5	3.0	0.2	630	11.0	0.7
		10.0	2.1	5.6	6.0	3.2	0.2		11.4	0.7
Dark, deep										
black sand	0-5	10.0	1.5	1.8	16.0	5.0	0.3	518	10.6	0.8
Spodosol		10.5	1.5	1.8	21.0	6.0	0.3		10.0	0.8
trees	20-25	10.0	1.5	2.0	10.0	3.8	0.1	364	8.0	0.7
20 m		9.5	1.4	2.0	9.0	3.2	0.1		8.5	0.7
Manacaparu										
Spodosol	0-5	10.0	1.3	6.3	12.0	4.5	0.4	644	10.0	0.7
		9.5	1.2	6.3	12.0	4.5	0.4		10.0	0.6
	20-25	11.0	1.3	4.8	17.0	5.5	0.3	728	23.5	0.5
		11.0	1.3	4.8	17.0	5.6	0.3		24.5	0.5

Table 3. (continued)
μ g/g

Site	Depth cm	Ca	Cu	Fe	K	Mg	Mn	N	Na	Zn
Blackwater Terra firme	0-5	15.0	0.9	11.0	12.5	5.5	0.5	700	14.0	1.0
		9.5	1.2	6.3	12.0	4.5	0.4		10.0	0.6
	20-25	11.0	1.3	4.8	17.0	5.5	0.3	728	23.5	0.5
		11.0	1.3	4.8	17.0	5.6	0.3		24.5	0.5
Blackwater Terra firme Spodosol	0-5	15.0	0.9	11.0	12.5	5.5	0.5	700	14.0	1.0
		15.0	0.9	12.5	13.0	5.0	0.5		15.5	0.9
	20-25	19.0	0.8	6.3	11.0	5.0	0.5	742	11.0	0.6
		19.0	0.9	5.8	11.0	5.3	0.5		11.0	0.6
Low forest Spodosol trees 35 m	0-5	10.0	1.4	15.0	27.5	7.0	0.3	2660	22.5	0.6
		11.0	1.4	15.0	27.5	7.3	0.3		22.5	0.6
	20-25	10.0	1.1	6.8	20.0	3.0	0.1	1190	19.0	0.6
		10.0	1.1	6.8	20.0	3.2	0.1		19.0	0.6
Campina-like forest Spodosol	0-5	17.0	1.3	2.5	70.0	22.0	0.6		13.5	0.9
		17.0	1.3	2.5	74.0	23.0	0.6		14.0	0.9
	20-25	25.0	1.1	10.0	41.0	14.5	2.2		34.0	0.7
		25.0	1.1	10.0	41.0	14.5	2.2		34.0	0.6
Agricultural Oxisol AGL	0-5	15.0	2.5	18.0	27.0	10.9	1.0	2016	14.0	0.8
		15.0	2.5	18.0	26.5	10.6	1.0		14.0	0.9
	20-25	15.0	2.2	9.0	22.5	6.5	1.5	1036	12.5	0.8
		15.0	2.3	9.0	21.5	6.5	1.5		12.0	0.7
Terra firme Primary forest trees to 50 m	0-5	20.0	1.3	19.8	42.5	17.5	1.0	3556	27.5	0.7
		20.0	1.3	19.8	42.5	17.5	1.0		27.5	0.7
	20-25	50.0	1.5	5.0	20.0	21.0	1.4	1610	19.6	0.5
		50.0	1.4	5.0	20.0	22.0	1.5		19.2	0.5
Punta Negra Spodosol	0-5	22.5	1.2	14.5	53.5	15.2	1.0	3975	23.5	0.7
		20.0	1.2	14.8	53.0	15.2	0.9		22.5	0.7
	20-25	10.5	1.4	4.8	20.0	6.8	0.3	1624	18.0	0.5
		10.0	1.3	5.0	20.0	6.6	0.3		18.0	0.5

Table 3. (continued)
r g/g

Site	Depth cm	Ca	Cu	Fe	K	Mg	Mn	N	Na	Zn
Terra firme Spodosol Small earth-worms, trees 30 m	0-5	17.5	1.9	25.0	39.0	13.0	1.0	2800	29.3	0.7
		17.5	1.9	25.0	39.0	13.0	1.0		28.0	0.7
	20-25	10.0	1.5	7.0	28.0	4.2	0.4	1400	25.0	0.6
		10.0	1.5	7.0	28.0	4.0	0.4		25.0	0.5
Oxisol	0-5	25.0	1.1	10 0	41.0	14.5	2.2	3010	34.0	0.7
		25.0	1.1	10.0	41.0	14.5	2.2		34.0	0.6
	20-25	13.0	1.5	3.3	15.0	6.2	0.3	1778	11.7	0.5
		13.0	1.5	3.8	15.0	6.2	0.3		13.0	0.5
Oxisol NAT	0-5	26.0	2.0	24 5	47.5	20.5	2.0	3220	12.0	1.0
		25.0	2.0	24.8	47.5	20.5	2.0		12.0	1.0
	20-25	14.0	1.7	5.5	26.0	6.0	1.7	1316	10.5	0.6
		13.0	1.7	5.3	26.0	5.6	1.7		10.0	0.6
Innundated muck	0-5	1350.0	1.9	7.5	80.0	170.0	143.8	1078	31.0	2.1
		1350.0	1.9	7.5	80.0	175.0	142.5		28.5	2.3
Varzea bank sediments, not recently flooded, but grazed.	0-5	1800.0	1.4	2.5	85.0	255.0	107.5	532	37.5	1.1
		1800.0	1.4	2.5	85.0	257.5	107.5		36.9	1.1
Campina Creek mud	0-5	47.5	1.0	2.0	47.5	18.5	1.6	**2450**	**40 0**	0.8
		47.5	1.0	2.0	47.5	20.0	1.5		41.2	0.8
Varzea dry site	0-5	118.5	3.0	30.0	72.5	37.3	5.5	3360	16.5	1.4
		116.0	3.0	31.0	70.0	37.3	5.5		16.5	1.4
	20-25	15.0	2.4	5.0	25.0	8.9	1.8	1050	13.1	0.9
		15.0	2.5	5.2	25.0	8.9	1.8		12.0	0.8

Table 4. Average total extractable soil cations (Ca, Cu, Fe, K, Mg, Mn. Na, Zn) from Brazil spodosols and oxisols.

Soil No.	Surface Soils 0-5 cm	Av.
9	Manacaparu Spodosol	44.8
4	Dark Sand Spodosol	48.9
1	Terra Firme Spodosol	53.2
10	Blackwater Igapo'	53.3
11	Blackwater Terra Firme	62.7
6	Lowland Spodosol	73.4
12	Agricultural Oxisol	79.6
2b	Campina on Sandstone	80.2
7	Lowland Spodosol	84.9
5	Lowland Spodosol	103.9
8	Terra Firme Spodosol	126.8
13	Oxisol	128.5
14	Punta Negra Spodosol	130.2
3	Terra Firme Primary For.	130.3
2a	Campina Spodosol	130.6
15	Oxisol Nat	135.2
16	Campina Creek Mud	161.6
17	Varzea-Dry Site	282.7
18	Varzea, inundated	1787.0
19	Varzea, not flooded	2290.9
	Subsurface Soils 20-25 cm	
4	Dark Sand Spodosol	35.3
1	Terra Firme Spodosol	38.9
10	Blackwater Igapo'	39.3
21	Campina on Sandstone	39.7
6	Lowland Spodosol	49.8
11	Terra Firme Spodosol	54.2
7	Low Forest Spodosol	60.3
14	Punta Negra Spodosol	62.0
9	Manacaparu Spodosol	64.5
15	Oxisol Nat	64.9
21	Varzea — dry site	71.7
12	Agricultural Oxisol	72.4
3	Terra Firme Primary For.	119.3
5	Lowland Spodosol	126.8
20	Campina Spodosol	128.5

Resumo

Estudos realizados próximo a Manaus, Brasil, em cooperação com o INPA, a fim de tentar estabelecer de que maneira o ciclo de nutrientes influencia a formação de "água preta" e "água branca". Medida a taxa de decomposição das folhas de **Caryocar villosum** sobre solos das ordens **spodsol** e **oxisol**, tanto em ambientes aquáticos como terrestres, com as folhas sem tratamento e tratadas com um bactericida, um fungicida ou um inseticida. Mediram-se ainda a quantidade de litter, as populações de animais e o teor de dez elementos biologicamente importantes no solo e no material vegetal em decomposição. Os resultados mostram diferenças consideráveis nas taxas de decomposição, bem como nos agentes e produtos finais da mesma, indicando estar a formação da "água preta" e da "água branca" intimamente ligada à taxa e tipo de decomposição, aos tipos básicos de solos e vegetação associada. Os sedimentos na água branca constituem exceção.

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