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THE EFFECTS OF LONGTIME AVOCADO CULTURE ON THE COMPOSITION OF SANDY SOIL IN DADE COUNTY

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This investigation was undertaken to determine the effect of 35 years of avocado grove culture on a sandy soil in Dade County. A second purpose was to learn more of the soil itself since no work has been published on its composition.

There are many reasons to expect profound changes in the soil as a result of commercial production of avocados. Presumably the soil retains part of the fertilizer which is so liberally applied in this area. Some losses are probable as the result of the application of fertilizer. The leaching of bases is accelerated by acid-forming nitrogen sources such as sulfate of ammonia and ammonium nitrate. Spray residues, particularly copper, accumulate in the soil.

The trees themselves contribute toward changes in the soil. Avocados produce and drop a relatively large quantity of organic matter. In addition to this they provide heavy shade which aids in the retention of the organic matter which reaches the ground. Trees contribute to losses from the soil as well as to the gains. The elements absorbed by the trees are lost, temporarily at least, from the soil. That portion which moves into the harvested crop is lost completely. Most of the remainder is eventually returned to the soil. Organic acids formed during the decomposition of organic matter accelerate leaching.

In order to measure the changes resulting from avocado culture, comparable grove and virgin soils had to be selected. It was assumed that before the grove was planted the two soils were the same and that no major change had taken place in virgin soils since the grove was planted. With these assumptions the difference between the two soils is a measure of the effect of the grove culture.

In order that the downward movement of the materials applied might be traced, a soil which could be sampled at several depths was desirable. Most Rockdale soils are too shallow for this purpose and are scarified in preparation for planting which makes them differ radically from virgin soil. The soil needed to be reasonably free from stones, in some areas at least, to allow even downward movement of water and to permit a sample to be taken without mixing several layers of soil. Since many of the changes would take place slowly, an old grove was needed for this study.

A suitable soil was found west of South Miami on the limestone ridge which lies along the eastern side of the County. The grove samples and virgin samples were taken less than 200 feet apart. The native plants in this area were mainly pine and saw palmetto. The soil was transitional between a Rockdale sandy loam, which as limestone over much of the surface and a Dade sand which has a clearly developed profile above the limestone. These soils are described elsewhere (18). Pockets were selected in both the virgin soil and the grove soil which were 24 inches deep. The A horizon in each case was 18 inches deep and the B horizon 6 inches. Immediately below the B horizon was the oolitic limestone. Adjoining these sand pockets the limestone extended to ground surface.

The virgin soil showed no evidence of having been disturbed. Judging by the size of the pine trees and the condition of the stumps the area was cut over 10 or 15 years before the samples were taken. Scars on the tree trunks and the general condition of the ground cover indicated the area had been burned a year or more before the samples were taken.

The soil in the grove was not scarified before the trees were planted. Furthermore, it was not cultivated during most of the 35 years since it was planted. For a time it was neglected and then had to be disced to bring weeds under control. When the samples were taken the branches of the avocado trees met in middles and the continuous shade kept the weeds from growing.

On the grove soil there was a layer of partially decomposed organic material from one to two inches thick. The first three inches of mineral soil were high in organic matter and dark brown in color. The major portions of the fine roots of the avocado trees were concentrated in this layer. From 3-6 inches the amount of organic matter diminished rapidly and the soil became lighter in color. From 6-18 inches the soil was a light gray brown with no noticeable organic matter. The mineral fraction in the entire A horizon was sand. The B horizon, 18-24 inches below ground surface, contained some clay and had a yellow-red color. Each of these layers was sampled separately and the 6-18 inch layer was divided into a 6-12 and a 12-18 inch section to determine whether or not differences existed which were not reflected in the appearance of the soil. These samples were taken in mid-September before the fall application of fertilizer.

There was no deposit of organic matter on the surface of the virgin soil. The 0-3 inch layer was darkened by organic matter but there was no observable difference from 3 to 18 inches. Samples from the virgin soil were taken from the same depths as from the grove soil.

These samples were screened without drying. Sub samples were dried at 85°C. for moisture determination. Organic matter and totals were determined on oven dried soil. Eighty five degrees was used for drying in preference to 100° or above because decomposition of organic matter has been observed in similar soils at 100°C. At 85° no decomposition was observed.

Soil pH was determined on the moist samples using equal volumes of soil and water. A model G Beckman pH meter was used for the measurement.

Organic matter was determined by loss on ignition. A five gram sample of oven dried soil was heated to constant weight in a size 0 porcelain evaporating dish over a Fisher burner. Since these samples were very low in clay and free calcium carbonate this was a suitable procedure.

Ten gram samples of the undried soil were extracted with 50 ml. of water. The suspensions were stirred mechanically for three minutes and filtered through dry paper. The portion of the filtrate which ran through in three minutes was returned to the paper after which all of the filtrate draining in an hour was collected. Measurable quantities of nitrate nitrogen, phosphorus, potassium, calcium, and magnesium could be extracted from the grove soil by this procedure.

Water extraction was chosen for several reasons. It recovers all of the nitrate nitrogen. It has been used for the investigations of phosphorus and potassium levels in other groves in the area (20). Peech and Young (23) used water extraction as a measure of available phosphorus in an extensive survey of the citrus grove soils in Florida. Many other investigators have shown that water extraction is useful as a measure of the phosphorus available to plants (4, 6, 9, 10, 14, 21, 29), Water-soluble potassium has been found to be correlated with the availability of potassium to plants (12, 17). Although no record was found of relationship between water soluble calcium and magnesium and the availability of these elements to plants, the amounts of these elements in the water extract helped to give a clearer understanding of what was taking place in these soils.

A separate 10 gram sample of undried soil was extracted with 50 ml. of 5 percent acetic acid. The suspension was stirred and the extract filtered in the same way as the water extract. This procedure was chosen as comparable to an acid sodium acetate extraction but avoided the high concentration of sodium which would interfere with flame photometric determinations. It was a suitable extractant since the soils were very low in free carbonates. In addition to the five elements determined on the water extracts measurable amounts of copper and manganese were obtained in the acetic acid extracts.

On both the water and acid extracts nitrate nitrogen was determined by a brucine colorimetric procedure (19), phosphorus by a molybdenum blue procedure (22) and potassium, calcium, magnesium, copper, and manganese were determined on a Beckman DU flame photometer.

The total quantities of nitrogen, phosphorus, potassium, calcium, magnesium, copper, manganese, and iron in each of these samples were also determined. The total quantity of any element in the soil is the ultimate reserve of that element and as such is useful in determining the adequacy of the supply. In citrus groves in California, for example, low total soil phosphorus was more closely related to deficiency than either water soluble or acid soluble phosphorus (1). In addition the total quantities of the several elements might reasonably be expected to reflect longtime changes better than the more soluble fractions.

Total nitrogen was determined by the Kjeldahl procedure (3) on an oven dried sample. The remaining elements were determined on the perchloric acid extract of the residue from the organic matter determination. During the extraction the perchloric acid was evaporated on a hot plate until dense white fumes were given off assuring that any silica dissolved during the ignition was dehydrated and could be removed by filtration so that it would not interfere with the colorimetric determination of phosphorus. The silica residues were completely volitalized with hydrofluoric acid proving that the extraction recovered the total amounts of the elements determined. These determinations were run in duplicate.

Phosphorus was determined colorimetrically by the same procedure used for the water and acetic acid extracts (22). Potassium, copper, and manganese were determined on the perchloric acid extract using the flame photometer. Magnesium was also determined with the flame photometer but not until the iron had been removed by precipitation with ammonia. Calcium was precipitated as the oxalate and titrated with permanganate (3). Iron was determined colorimetrically with o-phenanothroline (22).

RESULTS

Table 1 contains the sample designations and the depths to which they correspond in the first two columns. The pH of the soil suspension and the organic matter content, expressed as percent of oven dried soil, is shown in columns three and four.

Table 2 shows the water soluble constituents in the two soils. The values shown are the amounts of each element present expressed in p.p.m. of oven dry soil. Only nitrate nitrogen and phosphate phosphorus were determined. Phosphorus could not be determined on the water extract of the virgin soil because of interference. Table 3 shows the acetic acid soluble constituents in the same manner as Table 2.

Table 4 shows the total quantity of each of eight elements in the two soils. The results are expressed in percent of oven dried soil.

Table 1. Designation, Sampling Depth, pH and Organic Matter Content of Virgin and Grove Soil.

Sample	Depth of Sampling inches	pH	Organic Matter oven-dry soil percent
Virgin Soil			
A_1	0-3	6.12	4.0
A_2	3-6	6.99	0.8
A_3	6-12	7.05	0.9
A_4	12-18	7.26	0.9
B	18-24	7.42	4.3
Grove Soil			
A_0	Above Mineral Soil	5.61	36.3
A_1	0-3	6.33	15.6
A_2	3-6	7.16	2.9
A_3	6-12	7.26	0.7
A_4	12-18	7.32	0.6
B	18-24	7.18	2.3

Table 2. Water-Soluble Nutrients in Virgin and Grove Soils.

Sample	N*	P	K	Ca	Mg
	Element				
	ppm oven-dry soil				
Virgin Soil					
A_1	0	--**	1.8	26	1.5
A_2	0	--	1.4	26	1.4
A_3	0	--	0.6	26	1.4
A_4	0	--	1.0	26	1.9
B	0	--	1.0	38	0.0
Grove Soil					
A_0	117	49.4	45.4	224	39.9
A_1	20	23.1	7.3	88	11.5
A_2	1	7.6	6.9	44	1.5
A_3	4	4.4	4.4	34	0.0
A_4	3	4.1	4.2	29	1.4
B	7	11.8	18.2	34	6.6

* Nitrate nitrogen only.

** Not determined.

Table 3. Acetic Acid Soluble Nutrients in Virgin and Grove Soil.

Sample	N*	P	K	Ca	Mg	Cu	Mn
	Element						
	ppm oven-dry soil						
Virgin Soil							
A_1	0	1.9	7.7	899	100	0	16
A_2	1	0.4	3.0	472	62	0	7
A_3	0	0.1	2.8	343	43	0	7
A_4	0	0.4	2.4	389	39	0	9
B	0	0.5	5.4	1064	113	0	5
Grove Soil							
A_0	117	422	260	4870	771	42	43
A_1	21	528	59	6111	648	33	26
A_2	4	193	27	1853	114	5	9
A_3	3	23	11	384	38	0	4
A_4	3	17	10	352	23	0	11
B	8	45	95	711	79	0	2

* Nitrate nitrogen only.

DISCUSSION

pH. In Table 1 it can be seen that both soils were slightly acid in the A_1 layer and neutral or slightly alkaline below this depth. The only real difference between the two soils was the distinctly acid organic layer which had accumulated on the surface of the grove soil. Otherwise there was less than 0.25 of a pH unit difference between the corresponding samples in the two soils, which is no more than would be expected from two samples taken from the same location. Except for the formation of an acid layer in which the availability of minor elements might be expected to be much higher than in the near neutral or alkaline soil there has been no appreciable effect on soil pH as a result of avocado grove culture.

Organic Matter. The organic matter content of the virgin soil, shown in Table 1, was highest in the A_1 layer, low and relatively constant in the A_2, A_3 and A_4 layers then increased again in the B horizon. This followed the observation on the soil color mentioned earlier.

In the grove there was a distinctly organic layer above the mineral soil and the A_1 layer contained far more organic matter than would normally be found in a mineral soil in South Florida. Even the A_2 layer, 3-6 inches, contained almost as much organic matter as the A, layer of the virgin soil. As in the virgin soil the A_3 and A, layers were low in organic matter and approximately the same and the B horizon showed a slight increase.

The A_1 layer in the grove soil contained approximately four times as much organic matter as the corresponding layer in the virgin soil. Although the A_2 layer in the grove soil also contained almost four times as much organic matter as the corresponding layer in the virgin soil, this was less than one fifth of the amount contained in A_1 layer. Below six inches the grove soil contained less organic matter than the virgin soil. This probably represents an inherent difference between the two profiles since there is no logical reason why the grove culture should lead to an accumulation of organic matter in the top six inches of soil and to the loss of organic matter below the six inches.

Several factors have led to the accumulation of surface organic layer in the grove while there was none in the virgin area. There was a much higher production of organic matter by the avocado trees compared to the native pine and palmetto. This difference was made possible by the liberal use of fertilizer in the grove since the avocados cannot maintain themselves on the virgin soil. Also there was very little shade in the woods compared to the grove and it has been shown that organic matter cannot be built up in exposed locations even with the use of cover crops and mulch (2). Furthermore, periodic fires have occurred in the virgin area while the grove has been protected.

Two general surveys of orange groves (15, 23) showed that grove soils contained more organic matter than similar virgin soils. The differences were very much smaller than was found in this avocado grove. Most of the orange groves were cultivated which would hasten the decomposition of the organic matter.

The conditions in the avocado grove were similar to the forest conditions described by Harmsen (16) as necessary for the accumulation of organic matter. There was no removal of organic matter from the grove and no cultivation to hasten decomposition. According to this author, approximately 300 years would be required to develop a stabilized condition so far as the organic matter content of the soil is concerned. With such an estimate in mind the increase in organic matter content extending to a depth of six inches in 35 years is reasonable.

Table 4. Total Plant Nutrients in Virgin and Grove Soil.

Sample	Element							
	N	P	K	Ca	Mg	Cu	Mn	Fe
	percent oven-dry soil							
Virgin Soil								
A_1	0.064	0.050	0.006	0.258	0.065	0.000	0.016	0.22
A_2	0.017	0.020	0.004	0.173	0.072	0.000	0.006	0.19
A_3	0.022	0.010	0.004	0.139	0.071	0.000	0.005	0.15
A_4	0.009	0.024	0.006	0.253	0.076	0.000	0.006	0.20
B	0.070	0.128	0.035	0.300	0.222	0.000	0.011	2.45
Grove Soil								
A_0	2.107	1.403	0.099	2.690	0.185	0.112	0.020	1.78
A_1	0.662	1.020	0.030	2.714	0.151	0.073	0.016	0.60
A_2	0.063	0.488	0.006	0.403	0.069	0.000	0.006	0.22
A_3	0.050	0.077	0.004	0.041	0.053	0.000	0.002	0.20
A_4	0.013	0.059	0.004	0.033	0.052	0.000	0.003	0.17
B	0.039	0.268	0.026	0.121	0.103	0.000	0.006	1.36

Nitrogen. In the virgin soil there was practically no nitrate nitrogen found at any depth. The total nitrogen content was highest in the A_1 and B horizon and although low was about equal to that of other virgin mineral soils in peninsular Florida (23). The total nitrogen content of the successive layers paralleled the organic matter content. Carbon-nitrogen ratios were calculated. First the organic carbon was calculated using the generally accepted factor of 1.742 times the carbon content equals the organic matter content of the soil. In the A_1 layer the ratio was 35.3-1 and in the B horizon 35.9-1. With these very wide carbon-nitrogen ratios no nitrate nitrogen would be expected since the micro-organisms which decompose carbohydrate material would utilize the nitrogen as quickly as it became available.

The grove soil, in contrast to the virgin soil contained an abundant supply of nitrate nitrogen. The results with the water extraction and acetic acid extraction were the same within the limits of error of the method. This was to be expected since nitrates are not absorbed by the soil colloids. The nitrate content dropped from a very high value in the A_0 to a low level in the A_2 layer and below. This agreed with other observations that nitrogen applied to the surface did not increase appreciably the concentration of nitrate nitrogen below six inches. (5).

The total nitrogen in the grove soil, shown in Table 4, was high at the surface. The nitrogen content of the A_0 layer was as high as that of a muck soil (23). As with the nitrate, total nitrogen decreased very rapidly with depth. The A_2 layer contained only one tenth as much as the A_1. The nitrogen content of the grove soil also paralleled the organic matter content. The carbon-nitrogen ratios were very different at the surface and below. The ratio of the A_0 layer was 9.9-1 in the A_1 layer it was 13.5-1 and in the B horizon 33.8-1. The comparatively narrow ratios at the surface indicate that nitrogen should be readily available and agreed with the observed nitrate levels. The small amount of nitrate nitrogen found in the B horizon was probably carried from the surface by rain water rather than the result of the decomposition of the organic matter in that horizon.

The build-up of nitrogen in the grove compared to the virgin soil represented a very real gain in fertility since the nitrogen was readily available, as indicated by the low carbon-nitrogen ratios and the presence of large amounts of nitrate nitrogen. This buildup was due to nitrogen applied in the fertilizer. The nearly equal carbon-nitrogen ratios in the B horizons of the two soils strongly suggest that little or no modification of the organic matter in the grove soil resulted from the grove culture. The significant difference in nitrogen contents of the two soils was limited to the first 12 inches of mineral soil.

Phosphorus. The acetic acid-soluble phosphorus was low in all layers of the virgin soil. This is in agreement with the general observation that the soils of this area are too deficient in phosphorus for the growth of cultivated crops. The total phosphorus content of the A horizon, taken as a whole, shown in Table 4 was below the critical level established for citrus in California (1). The distribution of total phosphorus was quite different from the distribution of organic matter and nitrogen. The B horizon was much higher in total phosphorus than the A horizon. The top three inches of the A horizon did contain more phosphorus than the lower layers. This was probably maintained by leaf drop.

The grove soil contained very large amounts of water-soluble phosphorus. All of the layers contained more water-soluble phosphorus than soils in which response to phosphate fertilizer could be expected according to many investigators (4, 6, 9, 10, 25). In the 0-6 inch layer this soil approached the 32 ppm. watersoluble phosphorus at which a copper deficiency was induced in citrus (30). These levels were also higher than the average of 15 groves on the Rockdale soil, none of which showed any evidence of phosphorus deficiency (20). The water-soluble phosphorus was highest in the A_0 and decreased with depth to the B horizon. In the B horizon it was slightly higher again. The distribution of the acetic acid-soluble phosphorus was only slightly different. This fraction was higher in the A_1 than in the A_0 but otherwise the distribution was the same.

The total phosphorus values were very high in the upper layers of the grove soil. In the A_0 and A_1 the phosphorus content approached that of a fertilizer. The phosphorus content of the soil decreased with depth through the A_4 and increased appreciably again in the B horizon.

Comparing the phosphorus content of the two soils, the A_1 layer of the grove soil contained 1000 times as much acetic acid-soluble phosphorus as the corresponding layer of the virgin soil. Even the B horizon of the grove soil contained 90 times as much acid-soluble phosphorus as the B horizon of the virgin soil. The A_1 horizon of the grove soil contained 20 times as much total phosphorus as the Ai layer of the virgin soil. The B horizon of the grove soil contained twice as much total phosphorus as the B of the virgin soil.

The relationship between the acetic acid-soluble and total phosphorus in the two soils points up the difference between the native and applied phosphorus. In the A_1 layer of the virgin soil 0.38 percent of the phosphorus was acid-soluble while in the grove soil 5.18 percent was soluble. In the B horizons only 0.04 percent of the phosphorus was soluble in the virgin soil while 1.68 percent was soluble in the grove soil. These differences indicate that the phosphorus in the grove soil was present in a different compound or was located on the surface of the soil particles where it could be more readily dissolved than in the virgin soil.

There was significant movement of phosphorus to the 18-24 inch depth in the grove soil. Not only was the acid-soluble and total phosphorus higher in the B horizon of the grove soil than in the virgin soil but also the proportion of the phosphorus soluble in acetic acid was very much higher in the grove than in the virgin soil.

The accumulated phosphorus in the grove soil represents an active reserve, as is shown by the high levels of water-soluble and acid soluble phosphorus. The maximum build-up of phosphorus was at the surface where the fertilizer was applied. This was also where the greatest build up of organic matter and nitrogen was found. The movement of the phosphorus in the soil was not directly related to the organic matter content of the soil, however, since the phosphorus content of the B horizon in the grove soil was higher than in the virgin soil while the reverse was true of the organic matter contents.

The conclusions drawn in this investigation concerning the movement of phosphorus in the soil contrast with those in most studies on soil phosphorus. Two investigators found that no movement of phosphorus could be detected more than three inches below the point of application (8, 13) and another found only slight movement below six inches (26). In all cases the time over which the movement was measured was relatively short and the soils were heavier in texture than the one studied in this investigation. The relatively large accumulation of organic matter in this grove probably contributed to the movement of phosphorus since it has been shown that readily decomposable substances increase phosphorus availability (11). Mulching was effective in increasing the phosphorus content of apple leaves (27) and the rate of penetration of phosphorus in the soil (28). There are many reports of accumulations of phosphorus in orchard soils (9, 21, 23, 24).

Potassium. The virgin soil was uniformly low in both water-soluble and acetic acid soluble potassium, as shown in Tables 2. and 3. The total potassium was uniformly low in the A horizon but was much higher in the B horizon. The lack of any significant soluble fraction indicates that this potassium was bound too strongly to be of benefit to any but the slowest growing trees with low potassium requirements.

The water-soluble potassium content of the grove soil was low compared to the September average of 15 groves in Dade County over a three year period which was 65 ppm. (20). The samples in this grove were taken before the fall fertilizer was applied. Furthermore, the greater depth of this soil and the relatively low proportion of rock meant that the potassium present would be far more dilute than an equal amount would be in an average Rockdale soil.

The acetic acid-soluble potassium was from two and a half to eight times as high as the water-soluble potassium. The widest ratio between the two fractions was in the B horizon indicating a more effective exchange mechanism than the A horizon.

Total potassium shown in Table 4, was from 1.6 to 5.1 times as high as the acid-soluble potassium. This indicates that a relatively large proportion of the total potassium in the soil was available to plants in all layers.

The distribution of potassium which could be extracted with water and acetic acid and of total potassium followed the same pattern. The highest values were in the A_0 layer. The potassium level declined through the A_3 layer and A_4 was about equal to A_3. In each case the potassium was higher again in the B horizon. This agrees with the work of Peech and Young (23) who found that potassium was generally higher in the 0-6 inch layer than in the 6-12 layer.

In comparing the grove and virgin soils the grove contained more water-soluble and acetic acid-soluble potassium at all depths than the virgin soil and contained more total potassium in the A_1 layer. The surface organic layer with its high potassium content did not even exist in the virgin soil. For all practical purposes the two soils contained the same amount of total potassium in the A_2, A_3, and A_4 layers. The total potassium content of the virgin B horizon was higher than that of the grove.

Not only was the amount of soluble potassium greater in the grove soil but the soluble fraction represented a larger portion of the total. As an extreme example only one and a half percent of the total potassium in the B horizon of the virgin soil was soluble in acetic acid whereas 24.7 percent of the potassium in the grove soil was soluble.

While the available potassium in the grove was higher than in the virgin soil it is probable that the virgin soil contained more potassium at the outset. The B horizon of the virgin soil was much higher in total potassium than the B horizon in the grove soil but a much lower percentage was soluble. This indicates that the potassium in the virgin soil was held within the soil minerals while the large portion of the potassium in the grove soil was exchangeable. It seems probable that most of the readily soluble potassium in the grove soil came from the fertilizer applied or from falling leaves.

Unlike nitrogen and phosphorus, potassium has not accumulated in the grove soil to any appreciable extent, even though over the years it has been added in equal or greater quantity. Potassium was retained only where an exchange reaction could take place. The surface organic matter retained a small amount and in the B horizon a little was held by the clay.

Calcium. The water-soluble calcium content of virgin soil was low and uniform through the A horizon and slightly higher in the B. The calcium extractable with acetic acid decreased from A_1 to the A_3 layer. The acid-soluble calcium in the A_3 and A_4 layers was the same. The B horizon had the highest acid-soluble calcium content in the profile. Acetic acid extracted from 13 to 26 times as much calcium as water.

The total calcium content of the virgin soil decreased from the A_1 to the; A_3 layer. The A_4 layer was equal in calcium content to the A_1 layer. As with the partial extractions calcium was highest in the B horizon. The calcium content of all layers was extremely low considering that this soil was not only of limestone origin but also that the bedrock extended to the ground surface only a few inches away from the place where the sample was taken.

In the grove soil in contrast to the virgin soil there were great changes in the water soluble calcium in the A horizon. The A_0 contained six or seven times as much soluble calcium as the layers below six inches. From the A_0 layer the water-soluble calcium decreased rapidly through the A_3. For practical purposes the calcium content of the A_3, A_4 and B horizons was equal.

The distribution of the acetic acid-soluble and total calcium in the grove soil followed the same general pattern with one exception. The A_0 layer was slightly lower in the acid soluble calcium than the A_1 The two layers contained practically the same level of total calcium. Both fractions decreased from the A_1 to the A_3 layer. The A_3 and A_4 layers contained equal amounts. The B horizon was high again in both.

The calcium content of the grove soil was higher in the A_0, A_1 and A_2 layers than in the virgin soil regardless of the method of extraction of the calcium. The water-soluble and acetic acid-soluble calcium was approximately equal in the two soils in the A_3, A_4, and B horizons. The total calcium was higher in the virgin soil than in the grove below 12 inches. The fraction of the total calcium soluble in acetic acid was generally higher in the grove soil than in the virgin soil. Also the fraction acid-soluble increased with depth in the grove soil but decreased with depth in the virgin soil.

While the grove culture, particularly the application of fertilizer, has raised the calcium content of the A_0, A_1 and A_2, it has had no effect below these layers. The water-soluble and acetic acid-soluble calcium is essentially the same in the two soils below 12 inches. The difference in total calcium below 12 inches probably was an initial difference in the two soils.

Magnesium. The water-soluble magnesium content of the virgin soil was low at all depths. There was no layer of high solubility. With the acetic acid extraction on the other hand the magnesium content of the A_1 was high and decreased with depth through the A_4 layer. It was high again in the B horizon, even higher than in the surface three inches. There was no similarity between the relative amounts extracted from the various layers with water and acetic acid.

The total magnesium content of the virgin soil showed still another pattern of distribution. While it was relatively constant throughout the A horizon, the B horizon contained about three times as much total magnesium as the A.

The amounts of water-soluble magnesium in the different depths of the A horizon in the grove soil were quite different. As with most of the other elements the A_0, layer contained the most magnesium. There was about one fourth as much water-soluble magnesium in the A_1 layer as in the A_0. The water-soluble magnesium was low in the A_2, A_3, and A_4 but higher again in the B. The acetic acid-soluble magnesium decreased steadily from the A_0 through the A_4 and was only slightly higher in the B horizon.

The total magnesium was highest in the A_0 layer of the grove soil and decreased rapidly to the A_3, layer. The A_3, and A_4 layers contained about the same amounts and the B horizon contained about twice as much as the A_3 and A_4 layers. The general pattern of distribution was similar with all methods of extraction but the relative portion of the total soluble in acetic acid was very different at the surface and in the B horizon. In both the A_0, and A_1 layers nearly half of the total magnesium was soluble in acetic acid. In the B horizon, on the other hand, the soluble fraction amounted to less than one tenth of the total.

By all methods of extraction the A_0 and A_1 layer of the grove contained more magnesium than the virgin soil. However, the acetic acid soluble magnesium was low in the grove soil in the A. layer and below the virgin soil contained more total magnesium from the A_2 layer down. The abrupt rise in the water soluble magnesium in the grove soil in the B horizon when there was none in the virgin soil suggests that although magnesium moved in this soil once it got below the accumulated organic matter in the surface layers it was not retained by the soil but washed out with the excess water. The fraction of the total magnesium soluble in acetic acid was much higher in the grove A_0, A_1, and A_2 layers than in the virgin but below the A_2 both soils were the same.

A small reserve of available magnesium has been accumulated in the top six inches of the grove soil. Not only did the grove soil contain more magnesium to this depth but the magnesium was more soluble. The water soluble magnesium was the only fraction affected by the grove culture below six inches and this was such a minor fraction that it was unimportant. There are two reasons for the relatively small build up of magnesium compared to calcium and phosphorus. In the first place it was only recently that magnesium was included in fertilizer for avocados and secondly in this soil magnesium was almost as soluble as potassium.

Copper. Copper was not detectable in the virgin soil. In the grove soil measurable amounts were extracted with acetic acid from the An, A_0, and A_2 layers. The amounts found decreased very rapidly with depth. It was possible to detect total copper only in the A_0 and A_1 layers. This is somewhat inconsistent with the results of the acetic acid extract but probably was the result of the lack of sensitivity of the method. The soil extracts for total analysis were more dilute than the acetic acid extracts and contained more of the other elements which might interfere with the copper determination.

The accumulation of copper from spray residues and fertilizer in this soil amounted to approximately 850 pounds per acre. Furthermore, it was concentrated in the acid zone of the soil where it would be most readily available. Still no damage to the trees could be seen. One of the first symptoms of excessive copper in the soil is iron chlorosis and none was observed in this grove. The extremely high phosphorus content of the soil layers in which the copper was concentrated may have prevented injury since phosphates decrease copper availability (7, 30).

Manganese. Manganese soluble in acetic acid was detectable in all layers from the virgin soil. It was highest in the surface three inches and relatively uniform below that depth. The total manganese was also highest at the surface layer and relatively constant through the remainder of the A horizon. It increased again in the B horizon but was only two-thirds as high as in the A, layer. Roughly, ten percent of the total manganese was soluble in acetic acid.

In the grove soil the acetic acid-soluble manganese was highest in the A_0 layer with somewhat more than half as much in the AI. Below the A_1 the pattern of distribution was irregular. The distribution of total manganese was somewhat more orderly. The highest concentration was at the surface, it decreased sharply to the A_3, and increased again in the B horizon.

Except for the formation of the A_0 layer with a fairly high concentration of manganese there was little difference between the virgin soil and the grove soil. The patterns of distribution and the amounts found were the same. No great amount of manganese has been added to this grove and it appears that the virgin soil was quite well supplied with this element.

Iron. Only the total iron was run on the samples from these two locations. The iron content of the A horizon of the virgin soil was uniform. The B horizon contained approximately ten times as much as the A. In the grove soil the iron content followed the pattern of distribution of most of the other elements. It was very high in the A_0, decreased rapidly to the A_3 layer, was constant through the remainder of the A horizon and increased again in the B. While the grove soil was much higher in iron in the A_0. and A_1 layers than the virgin soil below this depth they were the same in the A horizon. In the B horizon the virgin soil contained twice as much iron as the grove soil.

The accumulated iron in the grove soil probably came from an impurity in the fertilizer since the iron content of avocado leaves is too low to account for such a large build up. As with most of the other elements the significant change in the iron content was limited to the top three inches of soil.

GENEHAL CONCLUSIONS

The level of plant nutrients in the virgin sandy soil was very low. While this soil contained sufficient calcium and magnesium for normal plant growth, even these elements were present in very small quantity considering its limestone origin. Manganese was the only element in the virgin soil which was relatively high. The pattern of distribution was the same for nearly all of the elements. Relatively high concentrations were found in the surface three inches where the plant nutrients were released as leaves and dead plants decomposed. The concentrations of plant nutrients dropped abruptly to a low uniform level below three inches or decreased with depth through the A horizon. There was an increase again in the B horizon. Differences in the total quantity of any element were often not reflected in similar changes in the water or acetic acid-soluble fractions.

Thirty-five years of avocado grove culture have brought about marked changes in this sandy soil. Perhaps the most significant change was the accumulation of an acid organic layer above the surface of the mineral soil which contained high concentrations of most of the elements required for plant growth. All of the changes, which could be traced, were greatest near the surface and diminished with depth. Most of the changes in the soil took place in the top six inches. In most cases the A_3 and A_4, layers were alike in composition as well as in appearance. Generally, the total and soluble fractions of each element showed similar patterns of distribution in the grove soil.

Phosphorus was the only element which moved in the grove soil to any significant extent and was retained at the lower depths. The total phosphorus content of the B horizon of the grove soil was twice as high as the total phosphorus content of the B horizon of the virgin soil.

In contrast, the B horizon of the virgin soil contained twice as much total calcium, magnesium, manganese, and iron as the grove soil. If the acetic acid-soluble potassium is deducted, the B horizon of the virgin soil also contained twice as much total potassium as the grove soil. The consistency of this relationship, with so many elements required in such different amounts by the trees, and applied in such different quantities in the fertilizer, is strong evidence that the B horizon of the virgin soil originally contained approximately twice as much of these elements and that this difference was not the result of the grove culture.

Where the amount of each element was increased as a result of the grove practices the fraction of the total which was readily soluble also increased. There are several reasons for this. The fertilizer salts applied to the soil are more soluble than the soil minerals. The elements contained in the leaves which fall are also more easily extracted than those in the mineral fraction of the soil. Since there was a large accumulation of organic material an increase in the soluble nutrients results. The elements held by exchange, either by the organic matter or the clay fraction in the horizon, are also easier to extract than those combined in the soil minerals.

The implications of this investigation are not limited to this particular grove and soil. Similar accumulations of nitrogen, phosphorus, and copper can be expected in other groves, when included in the fertilizer, magnesium, manganese, and iron can also be expected to accumulate. Accumulations of organic matter are evident in other groves where similar conditions exist. Since no substantial reserve of potassium was built up, regular maintenance applications of this element are required. The shallowness of most Rockdale soils is probably not a serious disadvantage so far as fertility is concerned since most elements applied in fertilizers are held in the first six inches of soil. Furthermore, even in this deep sandy soil, the highest concentration of roots was observed in the top three inches of the mineral soil.

Although no symptoms of injury were observed in this grove the accumulation of very large amounts of readily soluble phosphorus and copper suggest that these elements should be used more sparingly if eventual serious consequences are to be avoided.

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