Relationship between varying levels of copper and soil-pH on the growth and mineral composition of Arabica coffee plants[*]

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COMPENDIO

Se cultivaron en suelo árboles de Coffea arabica *L. (cv 'SL 34') y se trataron durante doce meses con todas las combinaciones de seis concentraciones de Cu (0, 5, 10, 50, 100 ppm Cu y una aspersión de 0,75 per cent Cu_2O) y tres niveles de pH del suelo (4,5 - 5,0; 5,5 - 6,0; 7,0 - 7,5)*

Se observó que los suelos ácidos (pH 4,5 - 5,0) que recibieron concentraciones de Cu mayores de 5 ppm dieron como resultado plantas de café con un crecimiento general retardado. Las hojas mostraron un contenido bajo de Fe y fueron severamente cloróticas en los tratamientos altos de Cu. Los suelos neutrales a alcalinos, aunque produjeron algo de clorosis en el follaje, se observaron que habían reducido grandemente los efectos retardatorios de las altas concentraciones de Cu, comparado con los tratamientos en los suelos ácidos. El pH del suelo casi neutral pareció ser el ideal para el crecimiento de las plantas de café, al compararse con el crecimiento más bien pobre en los suelos ácidos que recibieron varios tratamientos de Cu.

Comparando las plantas testigo con las asperjadas con Cu, se encontró que las plantas asperjadas mostraron un estímulo al crecimiento en todos los niveles de pH, particularmente en el suelo ácido que presentó aumento en el largo de los brotes y en el número de nudos, que los árboles en los niveles altos de pH. Este efecto se reflejó también en una concentración aumentada de elementos nutritivos minerales en varias partes de las plantas, comparado con plantas cultivadas en suelos con altos niveles de Cu y con los testigos. El Cu en las hojas fue más alto en las plantas asperjadas con Cu en relación con las no asperjadas. El aumento del pH del suelo por encima de 5,5 deprimió los efectos de la alta acumulación de Cu en el suelo y por consiguiente mejoró el crecimiento. — El autor.

Introduction

THE pH of any growth medium is an important factor that influences the availability and uptake of Cu by plants. Reuther and Smith (13), Reuther *et al.* (14) working with maize, observed severe Cu induced chlorosis in plants growing under very acid conditions (pH below 5.0) and high soil-Cu content. They noted that heavy liming of the soil produced better plant growth by reducing the toxic effects of excess Cu.

In Kenya, Arabica coffee is grown in soils of differing pH levels, ranging from below 4.0 at the Coffee Research Sub-station at Upper Kiambu, to 7.8 at Kalimoni estate near Thika (10). There have been suggestions that Arabica coffee can be produced more economically in soils of a moderately acid pH than in strongly acid soils (12).

No critical work has been reported, thus far in Kenya, on the Cu nutrition of coffee in relation to various pH regimes. Such a study is necessary in view of the frequent and continual use of Cu fungicide sprays on Arabica coffee grown in soils of varying pH. The purpose of this study was to examine, in soil-culture, the interaction between various concentrations of Cu and different levels of soil-pH on growth and nutrient composition of young Arabica coffee plants.

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Materials and methods

Soils from coffee plantations at the Upper Kiambu Sub-station of the Coffee Research Station, Ruiru, Kenya, were selected for their relatively strong acid characteristics (pH 4.3).

Soil samples were collected to a depth of 50 cm, thoroughly mixed, brought to the greenhouse and air-dried. About 5.5 kg of the soil was then put in each 25 cm, free-drainage 'PVC' plastic pots, painted black to control algal growth. To the soil in each pot were added 28 g of Ammonium Sulphate Nitrate (ASN) containing 26 per cent N; 168 g of Single Super Phosphate (SSP) containing 21 per cent P_2O_5, and 14 g of Chloride of Potash (KCL) containing 60 per cent K_2O. The soil mixture was kept moist with deionized rain water and incubated for a period of about four weeks to allow chemical reactions between soil and fertilizer to take place before planting the young coffee trees. In this manner a homogenous mixture of the added materials and soil was achieved. Prior to planting the trees, the pH of the soil in each pot was taken and then adjusted with "Magmax Green Label" (containing 26 per cent Ca and 18 per cent Mg), a liming and soil ameliorative material regularly used on coffee soils in Kenya.

Treatments

The treatments consisted of all combinations of three different pH ranges (4.5-5.0, 5.5-6.0, 7.0-7.5) and six copper concentrations (0, 5, 10, 50, 100 ppm Cu and a 0.75 per cent Cu_2O foliar spray). The various Cu levels were obtained by adding powdered Cu_2O at the appropriate amounts to the soil in each pot, or in the spray treatment by spraying once weekly a solution containing 0.75 per cent Cu_2O on the foliage. Each treatment was replicated three times. Hence there were 54 pots, with a single 2 year old coffee plant (cv 'SL 34') per pot.

The differential Cu treatments were commenced after two weeks of growth at the various pH levels. During the first month of treatment, some adjustments in pH were necessary. This was done by carefully removing the coffee trees, remixing the soil with an appropriate amount of "Magmax Green Label". In cases [illegible] .e pH was observed to be higher than expected, H_2SO_4 was added to lower the soil pH. After pH adjustment, the soil was replaced and the seedings replanted. It was not possible, however, to control the pH levels rigidly, due to the heterogeneity of the soil, the timelag in reaching equilibrium and the discriminatory mineral nutrient absorbing behaviour of the seedlings.

Moisture content was maintained by additions of deionized rain water as required. The surface soil in each pot was occasionally mixed in order to improve aeration and water penetration. Insect pests were controlled by monthly applications of 0.1 per cent fenitrothion (0,0-dimethyl -0-(3-methyl -4-nitrophenyl) phosphorothinate). In order to control mid-day temperature which was always above 20°C in the greenhouse, the foliage of the trees was occasionally sprayed with deionized rain water, the floor of the greenhouse flooded with running water and the ventilators switched on. This procedure was found to have reduced the greenhouse temperature considerably and to have increased the humidity.

Records

Visual observations of the effects of the various treatments on the foliage were made weekly, while observations on the roots were made at the end of the experiment, by carefully washing the roots after uprooting them from the pots. The rate of shoot growth was estimated by measuring the length of the shoot from the base of each plant to the terminal bud. Diameter of the stem was measured by taking the means of four readings around the stem at 3 cm from the base. The number of nodes, and floral buds were determined monthly. At the end of the experiment (after twelve months of treatment) the coffee plants, separated into leaves, wood and roots, were washed in 0.1 N HCl and 0.1 per cent Teepol, rinsed in deionized water and finally dried overnight in an oven set at 65°C. The composition of N, P, K, Ca, Mg, Mn, Zn, Fe and Cu in the plant and the nutrient content of the soil was determined as follows:

Soil samples

Air dried soil samples ground to pass through a 10-mesh nylon sieve, were analysed for pH in 1:2.5, Soil : 0.01 M $CaCl_2$ suspension using a glass electrode pH meter; total-N by the Kjeldahl's method, organic matter by the titration method of Walkley and Black; Available-P by the 0.5 M $NaHCO_3$ method of Olsen, exchangeable K, Ca, Mg, by the ammonium acetate leaching method and determined by atomic absorption spectrophotometry, while available-Cu was determined on an atomic absorption spectrophotometer after extraction with 0.05 M citrate - Na_2 EDTA solution.

Plant samples

The dry plant tissue samples were ground in a Wiley micro-hammer stainless steel mill using a 1 mm sieve. The ground samples were dried overnight at 100-105°C and then placed in a dessicator. Colorimetric determinations of total-N and P were carried out on a Technicon auto-analyser: N being determined by the alkaline sodium phenate-sodium hypochlorite method and P by the molybdo-vanadate method for the simultaneous determination of N and P in a micro-kjeldahl N-free H_2SO_4/selenium digest solution. Concentrations of K, Ca, and Mg were determined by dissolving the ashed samples in 0.5 N HCl, and Fe, Cu, Zn and Mn were determined in nitric-perchloric acid digest solution and read on an atomic absorption spectrophotometer.

Table 1.—Morphological observations on the growth of coffee in soil culture at various levels of Cu and pH.

Cu Treatments	Soil - pH levels		
	4.5 - 5.0	5.5 - 6.0	7.0 - 7.5
Control	Depressed growth chlorotic leaves, slight defoliation, some lateral root tips were necrotic	Vigorous to normal growth of leaves and roots.	Slightly depressed growth; young leaves normal, old leaves severely chlorotic with necrotic patches; normal root growth.
5-10 ppm Cu	Severely necrotic, defoliation, root growth slightly reduced	Normal growth; some necrosis on older leaves, normal root growth.	Fairly normal growth; severely necrotic older leaves and slightly reduced root growth.
50-100 ppm Cu	Leaves were severely chlorotic, later turning necrotic; severe defoliation, die-back of shoots; severely depressed growth; roots were dark brown in colour	Leaves were severely chlorotic turning necrotic; severe defoliation, d'e-back of shoots; severely depressed growth; roots were dark brown in colour.	Leaves were severely chlorotic, turning necrotic; severe defoliation, die -back of shoots; severely depressed growth; roots were dark brown in colour.
0.75% Cu_2O foliar spray	Very healthy growth; tips of some leaves were slightly necrotic, normal root development	Healthy foliage growth, and vigorous root development	Young leaves were chlorotic and later necrotic; reduced root growth

Results

Morphological observations

The first symptoms from the high Cu treatments, marked by generally reduced growth of the coffee plants, appeared on the foliage one month after the commencement of the treatment. At the end of the experiment, severe reduction in growth, accompanied by chlorosis and necrosis on the foliage and pronounced tip burn of roots were observed at the higher Cu levels.

Table 1 shows differences in symptoms produced in coffee plants as a function of Cu levels and soil-pH.

The control coffee plants grown in very acid soils (pH 4.5-5.0) showed slightly depressed growth, and severe chlorosis in the leaves which finally resulted in the defoliation of mature leaves. These symptoms became more pronounced at the 5-10 ppm Cu treatments. There were numerous shortened internodes and fewer branches. At higher Cu concentrations (10 ppm Cu) the plants were obviously wilted with pronounced chlorosis in younger leaves and severe necrosis in the more mature leaves. Die-back of the root system of the affected plants showed rootlets with an abnormally dark colored appearance.

Foliar sprays of Cu, on plants grown in low soil-pH, produced healthier growth than control plants, with only slight necrosis at the leaf-tips; also root growth was more vigorous.

In medium acid soils (pH 5.5 - 6.0), the control plants produced normal, and sometimes vigorous growth. Growth declined slightly in plants receiving Cu concentrations from 5 to 10 ppm, with some chlorosis and necrosis in older leaves; root growth of these plants, however, was normal. At Cu treatments greater than 10 ppm, the symptoms were identical to those observed at similar Cu concentrations in the very acid soils. Copper sprayed plants (at this medium acid soil pH level) were vigorous in growth and without any necrotic symptoms.

In alkaline soils (pH 7.0 - 7.5) the younger leaves of the control plants were normal in appearance, but the older leaves had scattered chlorotic and necrotic patches. The roots were slightly necrotic. Copper concentrations of 5-10 ppm, produced chlorosis in the young leaves and severe necrosis in the older ones, while the growth of the roots was slightly reduced. At still higher Cu concentrations (50-100 ppm Cu) complete death of the shoots was observed. The roots were severely reduced in growth, dark colored and without signs of new growth. These symptoms closely resembled those observed in plants growing in the other soil-pH regimes and receiving similar Cu concentrations. The Cu sprayed plants in the alkaline soils showed both chlorosis of the leaves, particularly in the young leaves, and some slight necrosis of the root tips.

In general, foliar chlorosis was more pronounced in the Cu sprayed plants in the alkaline soils than in those grown in the medium acid and strongly acid soils.

Growth characteristics

High Cu concentrations, at various soil-pH levels, markedly affected some growth characteristics of the coffee plant, as indicated in Table 2.

Stem diameter

Control plants in the very acid soils (pH 4.5 - 5.0) showed the lowest increase in stem diameter

Table 2.—The effects of increasing Cu concentrations and various soil -pH on some growth characteristics in young coffee plants grown in soil culture.

Treatments	Per cent increase in stem diameter			Per cent increase in Shoot length			Per cent increase in Nº of nodes/plant			Total Nº of Flower buds		
	Soil - pH			Soil - pH			Soil - pH			Soil - pH		
	4.5-5.0	5.5-6.0	7.0-7.5	4.5-5.0	5.5-6.0	7.0-7.5	4.5-5.0	5.5-6.0	7.0-7.5	4.5-5.0	5.5-6.0	7.0-7.5
Control	7.1	14.3	17.0	9.3	14.7	15.7	29.3	40.0	55.3	16	26	14
5 ppm Cu	15.3*	15.0	18.0	2.3**	9.0**	7.3**	15.7*	26.0*	22.0*	24*	26	14
10 ppm	13.3*	12.0	10.9*	3.3**	4.7**	6.0**	19.3	28.3	30.3**	24*	25	21
50 ppm	1.3*	0.9**	0.9**	0.9**	0.9**	3.7**	11.0**	20.0**	15.6**	2**	5**	4*
100 ppm	0.9*	1.7**	3.3**	1.0**	0.9**	1.3**	11.7**	20.3**	19.3**	1**	1**	1*
0.75 per cent Cu_2O spray	7.7	8.0*	13.3	18.0**	10.0*	7.3**	42.7*	30.3	49.0	14	11**	17
Means	7.6	8.7	10.6	5.8	6.7	6.9	21.6	27.5	31.9	14	16	12

In this and the following Tables: * Indicates differences significant at 5 per cent level
** Indicates differences significant at 1 per cent level

relative to plants in the medium (pH 5.5-6.0) and alkaline (pH 7.0-7.5) soils. Copper treatments from 5 to 10 ppm significantly increased stem diameter of plants grown in the strongly acid soils, and at higher Cu concentrations, stem increase was drastically reduced relative to the control. There was no marked effect of Cu at 5 to 10 ppm on stem diameter but percent increase in stem diameter was significantly reduced at higher Cu concentrations in both the medium and alkaline soils.

Foliar application of Cu had no effect on stem diameter in the very acid soils relative to the control, but decreased it in the medium and alkaline soils.

Shoot length

The increase in shoot length was severely reduced at Cu treatments from 5 to 100 ppm at all soil-pH levels. Particularly, shoot length was almost nil at 50 and 100 ppm Cu.

The sprayed treatment interestingly showed the greatest increase in shoot length at the lowest soil-pH and a decrease at the other pH levels when compared to the control treatment.

Node Number

Plants in the control treatment produced more nodes at higher soil-pH levels (5.5-6.0, 7.0-7.5) than plants in the very acid soils (pH 4.5-5.0). Node number decreased at 5-10 ppm Cu concentration at all pH levels. The decrease was less at 100 ppm than at 50 ppm Cu.

The Cu sprayed plants showed a significant increase in node number in the very acid soil-pH relative to plants in the control and soil-applied Cu treatments. There was no significant effect in node number between the Cu sprayed and unsprayed plants growing in the medium and alkaline soil pH levels.

Flower bud number

Flower bud number was consistently the highest at the medium soil-pH level (5.5-6.0) and was unaffected by Cu level up to a concentration of 10 ppm Cu. Copper treatments from 5 to 10 ppm showed a significant increase in flower bud number in plants growing in the strongly acid soil over the control. Plants in the alkaline soil had same trend as those in the medium soil-pH soil. However, the number of flowers produced was lower. Copper concentration greater than 10 ppm sharply reduced flower bud production at all three soil-pH levels.

Foliar application of Cu decreased flower bud number in comparison with the control, except at the alkaline pH level.

Soil nutrient content

The available nutrient content of soils in the pots at the end of the experiment (Table 3) showed remarkable increases when compared to the fertility of the soils prior to treatments. This was due partly to additions of N, P, K, Ca and Mg in the fertilizer and partly to the effect of added Cu on nutrient availability. The final soil pH values were with one exception (50 ppm Cu, at pH 4.5-5.0) within the desired ranges.

Table 3 —Nutrient content of soils (adjusted to pH 4.5-5.0) at the end of the experiment.

Treatments	pH (1:2.5; soil: 0.01 M $CaCl_2$)	Per cent		m.e. per cent (extractable)				ppm air-dry soil	
		N	OM	K	Ca	Mg	Mn	P	Cu
Control	4.8	0.23	2.2	3.7	7.9	3.3	0.66	201	3
5 ppm Cu	4.6	0.27	2.6*	3.8	7.9	3.7	0.70	242	67*
10 ppm "	4.6	0.28*	2.2	3.7	6.8	7.0*	0.60	156	117**
50 ppm "	5.2	0.28*	2.7*	3.3	5.3	10.6**	0.61	191	531**
100 ppm "	4.9	0.23	2.8*	2.6	4.3*	10.0**	0.59	155	980**
0.75 per cent Cu_2O spray	4.6	0.23	2.6*	3.5	6.6	3.0	1.04*	202	6
Means	4.8	0.25	2.5	3.4	6.5	6.3	0.70	191.2	284.0
Before start of experiment +	4.3	0.11	1.8	0.1	0.2	1.0	0.11	36	1

\+ Same data, in this, and Tables 4 and 5

Total N in the strongly acid soil was significantly increased at the 10 and 50 ppm Cu treatments; soil-organic matter was increased at all treatments, except the 10 ppm Cu, treatments, while Mg and Cu were consistently increased with increasing Cu treatments when compared with the control. There appears to be no marked effect of treatments on soil-pH, -K, -Ca, -Mn and -P, except for a significant decrease in soil-Ca at 100 ppm Cu treatment and an increase in Mn in the sprayed soil.

Table 4 shows the final nutrient levels in the medium acid soils as affected by varying concentrations of Cu.

Application of various Cu concentrations to soils adjusted to pH 5.5-6.0, showed a marked decrease in soil-pH and an increase in Mg at the 50 and 100 ppm Cu rates relative to the control. Soil-Mn was increased at the 100 ppm Cu concentration. There was a highly significant increase in soil-Cu with increase in the rate of Cu treatment. Soil N, -OM, -K, -Ca and -P were unaffected by treatment when compared with the control. Copper spray application did not affect soil nutrient content, except pH which showed an increase over the control.

The pH values of the soil-applied Cu treatments in the alkaline soils were slightly lower than in the Cu spray soils, as indicated in Table 5.

The alkaline soil-pH showed marked increases in soil-N, -OM and -Cu at increasing Cu treatments from

Table 4 —Nutrient content of soils (adjusted to pH 5.5–6.0) at the end of the experiment.

Treatments	pH (1:2.5, soil: 0.01 M $CaCl_2$)	Per cent		m.e. per cent (extractable)				ppm air-dry soil (available)	
		N	OM	K	Ca	Mg	Mn	P	Cu
Control	5.8	0.18	2.4	3.2	17.9	5.0	0.60	188	9
5 ppm Cu	5.7	0.17	2.4	3.5	21.2	2.0	0.58	285	103**
10 ppm	5.7	0.21	2.0	3.5	19.5	3.6	0.55	196	113**
50 ppm	5.6*	0.22	2.3	3.6	15.7	15.0**	0.56	233	630**
100 ppm	5.6*	0.17	2.5	2.9	15.1	12.0*	0.30*	148	995**
0.75 per cent Cu_2O spray	6.0*	0.20	2.4	3.1	18.7	1.3	0.68	217	22
Means	5.7	0.10	2.3	3.3	18.0	7.0	0.55	211.2	311.7

Table 5.—Nutrient content of soils (adjusted to pH 7.0-7.5) at the end of the experiment.

Treatments	pH (1:2.5; soil: 0.01 M $CaCl_2$)	Per cent		m.e. per cent (extractable)				ppm air-dry soil (available)	
		N	OM	K	Ca	Mg	Mn	P	Cu
Control	7.1	0.12	1.6	2.3	17.8	16.3	0.31	208	8
5 ppm Cu	7.2	0.15	2.5*	2.6	18.1	9.3	0.43	158	75*
10 ppm	7.1	0.18*	2.4*	3.0	21.3	7.3	0.53*	243	199**
50 ppm	7.1	0.17*	2.4*	2.2	18.5	18.0	0.45	232	445**
100 ppm	7.0	0.16*	2.5*	3.0	18.7	15.3	0.35	162	873**
0.75 per cent Cu_2O spray	7.4	0.16*	2.5*	2.5	18.3	9.3	0.44	190	16
Means	7.2	0.16	2.3	2.6	18.8	12.6	0.42	198.8	269.3

5 to 100 ppm. Soil-N was, however, unaffected at the 5 ppm Cu treatment relative to the control. Soil-pH, -K, -Ca, -Mg, -Mn and -P were unaffected at the various Cu treatments, although a marked increase in soil -Mn was observed at the 10 ppm Cu treatment. The Cu-sprayed treatments only showed increases in soil-N and -OM in comparison with the control.

Leaves

Table 6 shows the nutrient concentrations in the leaves of plants grown in soil at various Cu and soil-pH levels.

In the strongly acid soil (pH 4.5-5.0), increasing the rate of soil-applied Cu markedly decreased leaf

Table 6.—Nutrient element concentration in the leaves of young coffee plants as affected by Cu concentrations and soil-pH

Treatments	Soil-pH	Macro-nutrients (per cent in DM)					Micro-nutrients (ppm in DM)			
		N	P	K	Ca	Mg	Mn	Zn	Fe	Cu
Control	4.5-5.0	5.1	0.26	3.8	1.9	0.21	335	107	171	51
5 ppm Cu		4.9	0.16*	2.7*	1.8	0.19	204*	138	103	76
10 ppm		4.6	0.20	2.6*	1.1*	0.22	238*	98	82*	75
50 ppm		3.4*	0.28	1.5**	0.9*	0.20	330	76	71*	87
100 ppm		2.8**	0.25	1.6**	1.0*	0.20	434*	66	70*	128*
0.75 per cent Cu_2O spray		5.0	0.24	3.4	1.2*	0.17	575**	74	129	135*
Means		4.3	0.23	2.6	1.3	0.19	352	93	104	92
Control	5.5-6.0	5.0	0.18	3.5	2.4	0.24	757	83	137	64
5 ppm Cu		4.3	0.21	2.4	2.8	0.22	910	98	137	100
10 ppm		3.9*	0.27**	1.6*	1.9*	0.23	705	108	87	196
50 ppm		3.4*	0.26**	2.3	0.9**	0.26	347	107	97	217
100 ppm		3.3*	0.24*	2.2	1.2**	0.25	685	83	95	211
0.75 per cent Cu_2O spray		4.8	0.26**	3.6	2.3	0.24	353	140	134	200
Means		4.1	0.23	2.6	1.9	0.24	631	103	114	164
Control	7.0-7.5	4.0	0.21	2.9	1.1	0.43	245	82	125	64
5 ppm Cu		4.1	0.21	2.7	2.8*	0.48	572**	88	97	68
10 ppm		4.2	0.22	2.7	1.8	0.50	923**	122	62	150
50 ppm		3.5	0.23	2.3	1.2	0.31	300	116	63	222
100 ppm		2.9*	0.22	2.4	0.9	0.23*	263	71	98	164
0.75 per cent Cu_2O spray		4.4	0.25	3.4	2.1*	0.55	512*	102	159	20
Means		3.8	0.22	2.7	1.6	0.41	469	96	100	114

-N, -K, -Ca, -Mn and -Fe, and increased -Cu. The effect of treatments was most felt at Cu levels from 50 to 100 ppm. Except for a significant decrease in leaf -P at 5 ppm Cu, leaf-P, -Mg and -Zn were unaffected by the various soil-applied Cu levels. Copper spray treatment had no effect on leaf -N, -P, -K, -Mg, -Zn and -Fe; however, a significant decrease was observed for leaf -Ca, and an increase in Mn and Cu, relative to the control treatment.

Plants grown in the medium acid soil (pH 5.5-6.0) showed a significant decrease in leaf -N and -Cu and an increase in leaf -P at the 10 to 100 ppm Cu treatments. Except for a decrease in leaf -K at the 10 ppm Cu treatment, other nutrient concentrations in the leaves were unaffected by the various soil-applied Cu treatments. Copper spray significantly increased leaf -P.

Copper at 100 ppm in the alkaline soil (pH 7.0-7.5) significantly decreased leaf -N and -Mg, while leaf -Ca was increased at the 5 ppm Cu, with a marked increase in leaf -Mn at Cu treatments from 5 to 10 ppm. Foliar spray of Cu markedly increased leaf -Ca and -Mn.

Wood

Nutrient concentrations in the wood of the coffee plants receiving various Cu and soil-pH treatments are shown in Table 7.

There was no appreciable effect of treatments on wood-nutrient concentrations of plants grown in the strongly acid soil-pH. Apart from inconsistent trends in N, Ca and Mn, increasing rate of Cu from 5 to 100 ppm, including the spray treatment showed increased wood-Cu concentration when compared with the control measurements.

In the medium acid pH level, Cu treatments from 50 to 100 ppm significantly increased wood -Mn and -Cu, while wood -Mg was increased at 50 ppm Cu and wood -Mn increased at the 100 ppm Cu treatments. Except for an increase in wood -P, Cu spray treatment did not affect the concentration of nutrients in the wood.

Copper treatments from 50 to 100 ppm increased wood -Mn of plants grown in the alkaline soil. Wood -Cu was significantly increased at increasing Cu treatment levels from 10 to 100 ppm. There was no effect of Cu spray treatment on wood nutrient concentrations.

Roots

The concentrations of nutrients in the roots, as affected by the Cu and pH treatments, are shown in Table 8.

Applying Cu from 10 to 100 ppm to plants grown in the acid soil (pH 4.5-5.0) significantly increased root -N, while Cu rates from 5 to 100 ppm increased root -P. Treatment effects on root -K was inconsistent. Copper treatment at 10 ppm decreased root -Fe. Root -Cu was increased significantly at the 100 ppm Cu treatment level. Copper spray showed a significant decrease in root -Fe when compared with the control.

Table 7.—Nutrient element concentration in the wood of young coffee plants as affected by Cu concentrations and soil-pH.

Treatments	Soil-pH	Macro-nutrients (per cent in DM)					Micro-nutrients (ppm in DM)			
		N	P	K	Ca	Mg	Mn	Zn	Fe	Cu
Control		3.0	0.29	1.7	0.4	0.11	186	89	167	44
5 ppm Cu		3.1	0.24	2.2	0.6	0.13	429	109	148	87
10 ppm		2.7	0.28	2.3	0.5	0.12	371	88	63	179*
50 ppm	4.5-5.0	2.7	0.26	1.6	0.7*	0.10	644*	95	103	141*
100 ppm		2.1*	0.26	1.3	0.4	0.09	231	63	119	173*
0.75 per cent Cu_2O spray		2.7	0.27	1.5	0.4	0.07	158	102	152	122*
Means		2.7	0.26	1.7	0.5	0.10	336	91	125	124
Control		2.7	0.21	1.7	0.4	0.11	103	98	125	59
5 ppm Cu		2.6	0.23	1.7	0.6	0.16	232	105	123	103
10 ppm		2.6	0.24	2.0	0.6	0.17	198	113	154	190
50 ppm	5.5-6.0	2.5	0.19	2.2	1.0*	0.19*	312	86	94	390*
100 ppm		2.5	0.19	2.0	0.8*	0.15	540*	81	73	473**
0.75 per cent Cu_2O spray		3.0	0.28*	1.8	0.4	0.10	128	102	138	100
Means		2.6	0.22	1.9	0.61	0.14	252	97	117	219
Control		2.4	0.28	1.3	0.5	0.21	32	76	100	44
5 ppm Cu		2.1	0.24	1.5	0.6	0.24	137	149	75	135
10 ppm		2.2	0.23	1.3	0.4	0.33	108	139	87	172*
50 ppm	7.0-7.5	2.1	0.23	2.1	0.9	0.42	348*	104	81	195*
100 ppm		2.1	0.23	2.0	0.4	0.33	425*	122	48	157*
0.75 per cent Cu_2O spray		2.1	0.23	1.8	0.6	0.31	217	119	163	17
Means		2.1	0.24	1.6	0.5	0.30	211	118	92	120

Table 8.—Nutrient element concentration in the roots of young coffee plants as affected by Cu concentrations and soil-pH.

Treatments	Soil-pH	Macro-nutrients (per cent in DM)					Micro-nutrients (ppm in DM)			
		N	P	K	Ca	Mg	Mn	Zn	Fe	Cu
Control		2.2	0.37	1.4	0.4	0.07	335	70	822	180
5 ppm Cu		2.1	0.18*	0.9*	0.4	0.08	351	60	639	384
10 ppm		1.5*	0.18*	1.2	0.4	0.08	446	56	302*	563
50 ppm	4.5-5.0	1.5*	0.12**	0.5*	0.3	0.04	218	62	343	1946
100 ppm		1.0*	0.16*	1.1	0.3	0.04	535	40	333	7308*
0.75 per cent Cu_2O spray		2.2	0.30	1.6	0.5	0.06	562	47	300*	60
Means		1.7	0.21	1.1	0.3	0.06	374	55	456	1740
Control		2.3	0.24	1.9	0.6	0.15	149	57	495	82
5 ppm Cu		1.8	0.15	1.0*	0.7	0.10	513	60	306	274
10 ppm		1.8	0.30	1.2*	0.5	0.08	279	58	219	496
50 ppm	5.5-6.0	1.8	0.11*	0.3**	0.4*	0.05*	264	93	370	1354*
100 ppm		1.5*	0.10*	0.2**	0.4*	0.05*	298	75	269	2729**
0.75 per cent Cu_2O spray		2.4	0.28	1.7	0.6	0.10	268	78	470	45
Means		1.9	0.19	1.0	0.5	0.08	261	70	354	830
Control		2.1	0.39	1.4	0.6	0.20	98	65	639	77
5 ppm Cu		2.2	0.37	1.5	0.7	0.28	208	55	420	219
10 ppm		1.9	0.21	1.1	0.4	0.14	277	50	339	341
50 ppm	7.0-7.5	1.3*	0.13*	0.2**	0.1	0.13	579**	68	218	1277*
100 ppm		1.4*	0.19*	0.6*	0.4	0.16	263	46	276	1202*
0.75 per cent Cu_2O spray		1.7	0.37	1.4	0.8	0.10	114	51	427	52
Means		1.7	0.27	1.0	0.5	0.16	256	55	386	528

significant decrease in P. Plant -Cu was increased at the 100 ppm Cu treatments. Copper spray treatment also showed marked decreases in plant -K, -Mg, -Mn and -Fe when compared with the control.

At Cu treatments ranging from 5 to 100 ppm in the alkaline soil-pH level, plant -P and -Fe were significantly decreased, while Cu treatments from 50 to 100 ppm resulted in decreased plant -N, -K, -Ca (at 100 ppm Cu only), -Mg and -Zn. Plant -Mn was increased at the 5 and 10 ppm Cu treatments and plant -Cu increased at Cu treatment rate from 50 to 100 ppm. Copper spray decreased plant, -P, -Zn, -Fe and significantly increased -Cu relative to the control.

Discussion

A comparison of growth records showed that a medium acid or slightly alkaline pH led to better shoot growth, the production of more nodes and a slightly more increase in stem diameter than was the case at the very acid pH. In respect to the number of flower buds counted, which has been correlated with yield of berries (9) the medium acid pH appeared to be optimal.

Even 5 ppm of added Cu led to a marked reduction in shoot growth and node number but it did not reduce stem diameter nor decrease the number of flower buds; at the extreme pH levels, there was in fact, an increase in flower buds. These facts are not necessarily contradictory because the flowers were produced on wood existing *before* the start of the experiment.

Copper treatments from 50 to 100 ppm in the medium acid soil showed marked decreases in root -P, -Ca, -Mg, while root -Cu was markedly increased relative to the control. A consistent decrease in root -K was observed at increasing Cu treatment levels. Copper spray did not affect root nutrient concentration. Copper treatments at 50 and 100 ppm in the alkaline soil showed significant decreases in root -N, -P, -K. Root -Mn was increased at the 50 ppm Cu treatments from 50 to 100 ppm markedly increased root -Cu relative to the control. Copper spray treatment did not affect root nutrient concentrations.

Total amount (g. or mg) of nutrients in the plant

The total amount of nutrients in the coffee plants, as influenced by Cu treatments under various soil-pH levels, is shown in Table 9.

Plants grown in the strongly acid soil and at Cu treatments levels from 5 to 100 ppm showed significant decreases in plant -P, -K (except for treatment at 10 ppm Cu), -Ca, -Zn, and -Fe in comparison to the control. Plant -N, -Mg, and -Mn were decreased at the 50 and 100 ppm Cu treatment. Copper spray treatment significantly decreased plant -Zn and Fe.

At Cu treatments from 5 to 100 ppm in medium acid soil, plant -N, -K, -Mg and -Fe were decreased, while Cu treatments from 10 to 100 ppm decreased plant -Ca, -Mn and Zn. Plant -P was unaffected by treatment, except at the 50 ppm Cu which showed a

Table 9.—Total amount of nutrient elements in g or mg in the whole coffee plant as affected by Cu concentrations and soil-pH.

Treatments	Soil-pH	Macro-nutrients (g)					Micro-nutrients (mg)			
		N	P	K	Ca	Mg	Mn	Zn	Fe	Cu
Control		4.1	0.36	2.7	1.1	0.15	11	3	15	3
5 ppm Cu		2.8	0.16*	1.6*	0.8	0.11	12	2*	9*	5
10 ppm		2.7	0.20*	1.7	0.6*	0.11	9	2*	5*	18
50 ppm	4.5-5.0	1.4*	0.12**	0.7**	0.3**	0.06*	7*	1**	4*	23
100 ppm		1.1*	0.12**	0.9*	0.3**	0.06*	7*	1**	3**	48**
0.75 per cent Cu_2O spray		3.9	0.31	2.6	0.8	0.11	14	2*	7*	4
Means		2.6	0.21	1.7	0.6	0.10	10	2	7	16
Control		5.4	0.34	3.9	1.8	0.27	18	4	13	3
5 ppm Cu		3.2*	0.21	1.9*	1.5	0.17*	18	3	6*	5
10 ppm		2.9*	0.27	1.4**	0.9*	0.14*	11*	2*	4*	7
50 ppm	5.5-6.0	1.5*	0.10*	0.9**	0.5*	0.09**	7*	1*	3**	12
100 ppm		1.7*	0.12	1.0**	0.6*	0.10*	11*	1*	3**	26**
0.75 per cent Cu_2O spray		3.6	0.29	2.4*	1.2	0.15*	8*	3	8*	4
Means		3.0	0.22	1.9	1.0	0.15	12	2	6	9
Control		3.7	0.38	2.4	0.9	0.36	5	3	13	2
5 ppm Cu		2.7	0.26*	1.9	1.3	0.32	10*	3	6*	4
10 ppm		3.1	0.24*	1.9	0.9	0.35	16**	3	6*	6
50 ppm	7.0-7.5	1.3*	0.12**	0.9**	0.5	0.16*	7	1**	2**	10*
100 ppm		1.4*	0.13**	1.1**	0.4*	0.15*	6	1**	3**	10*
0.75 per cent Cu_2O spray		2.5	0.25*	2.0	1.1	0.29	8	2*	7*	12**
Means		2.4	0.23	1.7	0.8	0.27	8	2	6	7

Applied Cu levels above 10 ppm were obviously highly toxic, as indicated by the very marked decrease in all parameters measured including the number of flower buds. These high Cu concentrations apparently interfered with the development of flower buds on wood already formed. At 10 ppm Cu, the growth parameters were clearly affected relative to the control (except stem diameter at pH 4.5-5.0 for which the control value seemed anomalous) and the increase in flower bud numbers at both the very acid and somewhat alkaline pH levels relative to the control, might possibly be regarded as flowers induced by stress caused by unfavourable soil-pH levels such as those obtainable in the strongly acid and alkaline soils.

Copper sprays had a relatively slight effect on some of the growth parameters. It should be noted, however, that shoot growth and the formation of nodes at the lowest pH level (4.5-5.0) were promoted by the Cu sprays, though, admittedly this result was significant only for the first character. The number of flower buds was decreased by Cu sprays, though not significantly. It seemed as though the Cu spray treatment had generally promoted plant growth relative to the control treatment, and hence producing a slight 'tonic' effect often observed in coffee after Cu spray applications (1, 4, 18).

In all respects, including morphologic symptoms, the effects of Cu added to the soil were most severe under very acid soil conditions. It should be noted, however, that the control plants thrived considerably less well at this soil-pH level. This fact may be explained by the ready availability of most heavy metals, as well as by the high concentration of H-ions *per se*. Reference to the undesirable effects of low pH on several plants has been made by Reuther and Smith (13), Seatz and Peterson (16), Dolar and Keeney (2).

In the present study, the highest accumulation of trace elements, particularly Cu (180-7308 ppm) was obtained in the roots, and to a lesser extent in the wood at the very acid pH level. It is inferred from this observation that under low soil-pH level (4.5-5.0) high Cu accumulation both in the soil and the roots would result in severe root injury and would adversely affect plant growth by hindering the absorption (by the roots) of other mineral elements. Ishizuka (5, 6) found that high root-Cu hindered nutrient translocation and arrested the meristematic activities in the roots.

At the high pH level (7.0-7.5), at least in the control, growth was not as favourable as under slightly acid conditions. This might be attributed to an inadequate availability of some trace elements, particularly, Fe and Cu (8, 11). Leeper (7) observed that Cu and other heavy metals are less mobile in alkaline soils, due to the formation of copper hydroxide, phosphate and other complexes, and since their atoms form covalent links and chelate compounds, they become tightly absorbed to the extent of not being available to plants. Following the findings by several workers (3, 15, 17) on other crops, it is inferred in coffee, from the data presented herein, that the adverse effects of excess Cu could be reduced by liming a very acid soil-pH to near neutral pH and at the same time, increasing the fertility status of the soil through fertilization.

Summary

Two-year old *Coffea arabica* L. (cv 'SL.34') trees were grown in soil culture and treated for twelve months with all combinations of six Cu concentrations (0, 5, 10, 50, 100 ppm Cu and 0.75 per cent Cu_2O spray) and three soil-pH levels (4.5-5.0; 5.5-6.0; 7.0-7.5).

It was observed that acid soils (pH 4.5-5.0) receiving Cu concentrations greater than 5 ppm resulted in coffee trees with generally stunted growth. The leaves showed low Fe content and were severely chlorotic at high Cu treatments. Neutral to alkaline soils although producing some chlorosis on the foliage, were observed to have greatly reduced the stunting effects of high concentrations of added Cu as compared with treatments in the acid soils. Near neutral soil-pH appeared ideal for the coffee plants when compared with the rather poor plant growth in the acid soil receiving varying Cu treatments.

Comparing the control plants with the Cu sprayed ones, it was found that the Cu-sprayed plants showed growth stimulating effects at all pH levels, particularly at the acid soil-pH which had increased shoot length and node number, than trees at the high pH levels. This effect was also reflected in increased concentration of mineral nutrient elements in various parts of the plants when compared with plants growing in soils applied with high Cu levels and the control. Leaf-Cu was highest in the Cu sprayed plants relative to the unsprayed ones. Increasing the pH of the soil above 5.5 depressed the effects of high Cu accumulation in the soil and hence improved growth.

Literature cited

1. ADUAYI, E. A. Effect of copper sprays on the mineral nutrient content and growth of Arabica coffee seedlings in Kenya. Communications in Soil Science and Plant Analysis 3:323-28. 1972.

2. DOLAR, S. G. and KEENEY, D. R. Availability of Cu, Zn and Mn in soils. 1. Influence of soil-pH, organic matter, and extractable phosphorus. Journal of the Science of Food and Agriculture 22:273-78. 1971.

3. HAMILTON, J. and GILBERT, S. G. Relation of fertilization with copper and nitrogen to copper - deficiency symptoms, leaf composition and growth of tung. Proceedings. American Society for Horticultural Science 50:119-24. 1974.

4. HOLLIES, M. A. Effects of shade on the structure and chlorophyll content of Arabica coffee leaves. Experimental Agriculture 3:183-90. 1967.

5. ISHIZUKA, Y. The toxic action of copper ions on the growth of rice plants. I-The toxic action of copper ions on the growth of rice plant when half of its roots in placed in solution of $CuSO_4$ with or without nutrients, Journal of the Science of Soil and Manure. Tokyo. 14:248-63. 1940.

6. ———— The toxic action of copper ions on the growth of rice plants. II-The abnormal accumulation of copper ion near the growth point of the root. Journal of the Science of Soil and Manure. Tokyo 16:43-45. 1942.

7. LEEPER, G. W. Factors affecting availability of inorganic nutrient in soils with special reference to micronutrient metals. Annual Review of Plant Physiology 3:1-16. 1952.

8. MITCHELL, R. C. Trace elements in soils. *In* Bear, F. E., ed. Chemistry of the soil. London, Reinhold Publishing, 1967. pp. 320-68.

9. MONTOYA, L. A., SYLVAIN, P. G., and UMAÑA, R. Effects of light intensity and nitrogen fertilization upon growth differentiation balance in *Coffea arabica* L. Coffee 3:97-104. 1961.

10. MUTISO, S. Yellow Cherry. Kenya Coffee 36:281-82. 1971.

11. OLSEN, C. Iron absorption in different plant series as a function of the pH value of the solution. C. R. Trav. Lab. Carlsberg 31:41-59. Taken from Soils and Fertilizers 21:393, (2304). 1956.

12. OMBWARA, C. J., ed. Coffee Growers' Handbook. Equatorial Publishers, Nairobi, Kenya, 1968. 112 p.

13. REUTHER, W. and SMITH, P. F. Effects of high copper content of sandy soil on growth of citrus seedlings. Soil Science 75:219-24. 1953.

14. ————, SMITH, P. F. and SCUDDER, G. K. Jr. Relation of pH and soil type to toxicity of copper to citrus seedlings. Proceedings of the Florida State Horticultural Society 66:73-80. 1953.

15. ———— and LABANAUSKAS, C. K. Copper. *In*, Chapman, H. D. ed., Diagnostic criteria for plants and soils. University of California, U.S.A. Chapter 11:157-79. 1966.

16. SEATZ, L. F. and PETERSON, H. B. Acid, alkaline, saline and sodic soils. *In* Bear, F. E., ed. Chemistry of the soil. London, Reinhold Publishing 1967. pp. 292-319.

17. SPENCER, W. G. Effect of copper on yield and uptake of phosphorus and iron by citrus seedlings growth at various phosphorus levels. Soil Science 102:296-99. 1966.

18. TRENCH, A. D. and McCLELLAND, T. L. Bordeaux spraying with particular reference to the leaf and berry fall of coffee. Nairobi, Kenya. Department of Agriculture Bulletin 17:1-16. 1932.