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Effect of Soil Management on Avocados in a Krasnozem Soil

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ABSTRACT

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Avocado trees, cultivar 'Fuerte', were grown under 7 soil management regimes on krasnozem soil at the Tropical Fruit Research Station, Alstonville. The regimes consisted of combinations of dolomitic, gypseous and nitrogenous amendments with cover cropping or a kikuyu sward, and a "bare ground" treatment as control. This paper describes the effects of these treatments on physical and chemical characteristics of the soil, on nutrient levels in the avocado leaves and on the occurrence and spread of *Phytophthora cinnamomi* in the trial site and on tree health, growth and yield of the avocado trees.

Treatments receiving dolomite or phosphogypsum achieved the desired high cation-exchange levels but did not influence the behaviour of *P. cinnamomi* in soil leachates or incidence of Phytophthora root rot.

Trees receiving phosphogypsum produced more fruit than trees receiving dolomite, although trees given dolomite grew faster. Inputs of fowl manure and cover cropping were the same in both treatments. Soil phosphate levels were significantly ($P<0.01$) higher in treatments receiving fowl manure and higher ($P<0.05$) in the treatment receiving phosphogypsum than in dolomite treatments, owing to the phosphate content of the gypsum. However, higher soil P levels were not reflected in higher leaf P levels.

Soil pH in the top 15 cm was raised and exchangeable Al lowered by applying dolomite, and pH decreased with increasing soil depth.

Trees developed Phytophthora root rot first where there was bedrock in the top 80 cm of the soil profile, but later root rot developed in trees growing mainly in the lowest part of the trial area. The principal factor affecting the incidence and severity of root rot in this trial was internal drainage, as determined by the presence of bedrock, weathering rock or high bulk density in the top 80 cm and by topography. Management treatments did not influence the incidence of root rot in this trial, or the production and size of fruit on affected trees.

A comparison of leaf analyses for healthy and root rot-affected trees over all treatments showed a dramatic reduction in some leaf nutrient levels in the diseased trees.

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Keywords: bulk density; dolomite; 'Fuerte' avocado; growth; leaf nutrients; nitrogenous amendment; phosphogypsum; *Phytophthora cinnamomi*; soil management; tree health; yield.

INTRODUCTION

Phytophthora root rot is the most important disease of avocados (*Persea americana* Miller) on the north coast of New South Wales (NSW). It is caused by the fungus, *Phytophthora cinnamomi* (Rands), which is widely distributed in Australian soils.

Studies of the incidence and severity of Phytophthora root rot in the seventies suggested that the disease might be controlled by suitable management practices. Broadbent and Baker (1974) found that those red basaltic soils in which few avocado trees declined owing to root rot had a high content of organic matter, high levels of exchangeable calcium and nitrogen tied up in the humic residues and high biological activity. They also suggested that the application of fowl manure plus dolomite and extensive use of cover crops could maintain the physical, chemical and microbiological properties of red basaltic soil at levels comparable to the natural rainforest situation. The theory that Phytophthora root rot might be suppressed under such conditions was supported by Pegg (1977).

Consequently, north-coast avocado growers are advised to grow green manure crops for 1 or 2 years before planting avocados, then to grow cover crops between the rows, to mulch around individual trees to a depth of 10–15 cm with grasses or cereals and to apply dolomite and nitrogen-rich fertilizer mixtures (Chalker, 1979).

Avocados do not grow well in poorly-drained soils, especially when *Phytophthora cinnamomi* is present (Goodall, 1955). Soil drainage characteristics have been used to determine if specific soil series are suitable for growing avocados in California (Burns et al., 1960; Zentmyer et al., 1967) and in South Africa (Wolstenholme and Le Roux, 1974). No such studies have been carried out in NSW, nor do we know whether management practices such as applications of dolomitic and gypseous amendments and cover cropping can alter fertility and drainage characteristics, and hence root rot incidence.

To test the effect of cover cropping vs. kikuyu sward and high vs. low levels of dolomitic, gypseous and nitrogenous amendments on avocado growth, yield and root rot suppression, a field trial was established at the Tropical Fruit Research Station, Alstonville, N.S.W. The site chosen for the trial was typical of the krasnozem soils on which avocados are grown on the north coast.

MATERIALS AND METHODS

Climate. – The climate at Alstonville (latitude 26°38′S) is sub-tropical with maximum rainfall in the late summer and early autumn, and a dry spring and

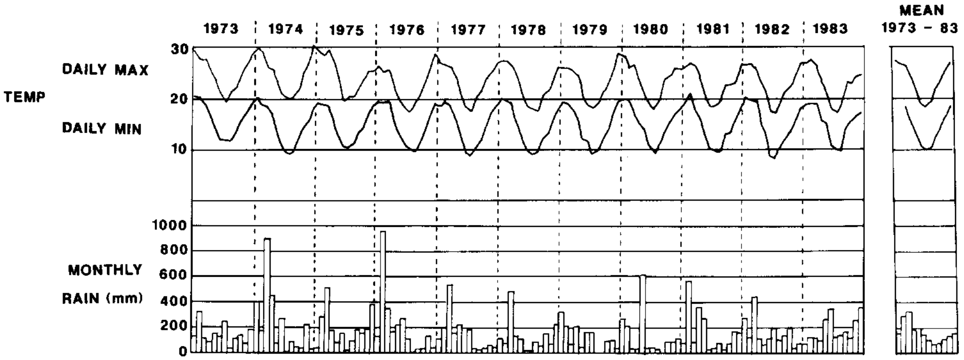

Fig. 1. Total monthly rainfall (mm) and mean daily maximum and minimum temperatures (°C) at the Tropical Fruit Research Station, Alstonville, 1973-1983.

early summer. Average annual rainfall over 47 years is 1670 mm. Periods of dry years alternate with periods of wet years (Nichols et al., 1953). Rainfall and temperature data (maxima and minima) over the trial period are shown in Fig. 1. Over the years 1973–1983 the range of temperatures (minimum-maximum) for the 2 high-rainfall months of February and March were 19.3–27.0 and 18.6–26.7 °C, respectively.

Soils. – The soil belongs to the Wollongbar association in which the dominant soil type is Wollongbar clay loam (Nichols et al., 1953) and is classified as a krasnozem (Stace et al., 1968). The surface soil is a reddish-brown clay loam which has a pronounced crumb structure and usually extends about 2.5 m below the surface. It overlies a red-brown friable clay also with crumb structure. Unweathered and weathering basalt rock occurs in the top 80 cm over much of the trial area (Fig. 2).

Treatments. – The trial was planted in a rectangular area on a northerly slope (12°) at the Tropical Fruit Research Station, Alstonville in 1973. The area consisted of 10 rows of avocado trees with 22 trees in each row. The trees were all 'Fuerte' cultivar grafted on to 'Fuerte' rootstock, planted in a 9×9 m configuration.

The trial was designed to compare 7 management regimes in 4 randomized blocks, with each plot consisting of 2 adjacent trees within a row, surrounded by buffer trees. However the blocks were not effective in controlling variation in tree growth and fruit yield, so these variables were analysed on a single-tree basis, with treatment means being corrected for row and column effects instead of block effects.

We aimed to determine whether, through the addition of dolomite, phosphogypsum and nitrogenous fertilizers and cover cropping, growth and yield of avocado trees could be improved and tree losses from Phytophthora root rot could be reduced on a krasnozem soil under sub-tropical conditions. Conse-

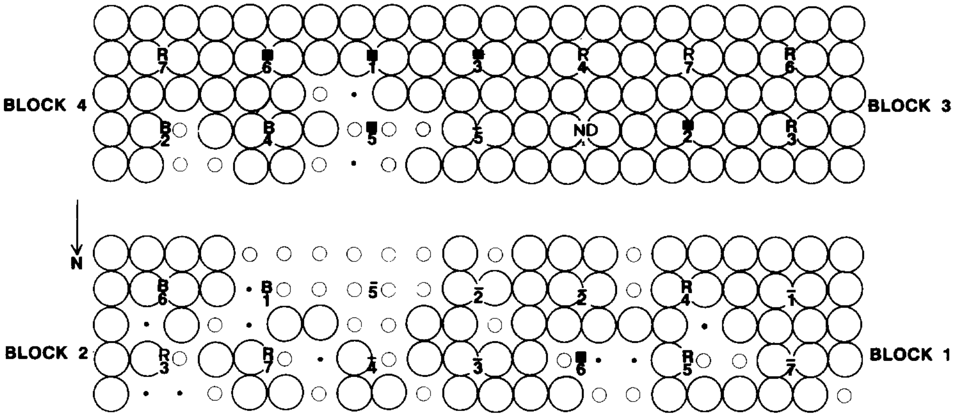

Fig. 2. Layout of the trial showing distribution of healthy (◯), unhealthy (○) and dead (●) trees in 1982 and areas of bedrock (B), weathering rock (R) and high bulk density (Mg m^{-3}) > 1.20 (■) in top 80 cm. Numerals indicate treatments within each block.

TABLE 1

Total weight of N, P, K, Ca, Mg and Na applied in Treatments 1-7 in 1979 and 1981

Treatment	Year	Element applied (kg $tree^{-1}$)					
		N	P	K	Ca	Mg	Na
(1) BG	1979	0.248	0.113	0.246	-	-	-
	1981	0.291	0.150	0.328	-	-	-
(2) KS	1979	0.248	0.113	0.246	-	-	-
	1981	0.291	0.150	0.328	-	-	-
(3) KS+Dol+Cal	1979	0.310	0.113	0.246	5.701	3.240	-
	1981	0.364	0.150	0.328	1.206	0.648	-
(4) KS+Dol+Urea	1979	0.310	0.113	0.246	5.670	3.240	-
	1981	0.364	0.150	0.328	1.134	0.648	-
(5) CC	1979	0.248	0.113	0.246	-	-	-
	1981	0.291	0.150	0.328	-	-	-
(6) CC+FM+Dol	1979	3.245	3.272	1.704	13.527	3.807	0.324
	1981	3.288	3.309	1.786	8.991	1.215	0.324
(7) CC+FM+Gyp	1979	3.245	3.361	1.704	24.138	0.567	0.344
	1981	3.288	3.327	1.786	11.113	0.683	0.328

quently the applications of N, P, K, Ca and Mg in some treatments were considerably greater than those applied under the conventional programme of a mown kikuyu sward (Table 1).

Basal fertilizer was applied in January, March and November in each year, at the rate of 150 g of fertilizer $tree^{-1}$ $year^{-1}$ of tree age at each application. N:P:K ratios were 5.0:7.3:4.0 in January, 9.6:2.6:6.6 in March and 9.6:2.6:16.7 in November.

The following management regimes were superimposed from 1973 to 1980:

(1) BG: bare ground extending beyond the root zone, with kikuyu (*Pennisetum clandestinum* L.) grown between rows for erosion control. Weed growth was suppressed by the herbicide Paraquat$^{(R)}$ (3 l ha^{-1}).

(2) KS: mown kikuyu sward.

(3) KS+Dol+Cal: mown kikuyu sward fertilized with 5 t ha^{-1} year^{-1} of dolomite and with calcium nitrate (at a level of N equivalent to 25% of basal N at each application) in November and April.

(4) KS+Dol+Urea: mown kikuyu sward fertilized with 5 t ha^{-1} year^{-1} of dolomite and with ureaformaldehyde (at a level of N equivalent to 25% of basal N at each application) in November and April.

(5) CC: cover crops: *Lablab purpureus* L. in summer, oats (*Avena sativa* L.) and lupins (*Lupinus angustifolius* L.) in winter.

(6) CC+FM+Dol: cover crops as above, fertilized with 10 t ha^{-1} year^{-1} of pelleted fowl manure 'Dynamic Lifter'$^{(R)}$, which had approximately 2.0:2.5:1.1 N:P:K., and with dolomite at 5 t ha^{-1} year^{-1}.

(7) CC+FM+Gyp: cover crops fertilized with 10 t ha^{-1} year^{-1} of pelleted fowl manure as above, and with phosphogypsum at 10 t ha^{-1} year^{-1}.

Barner grass (*Pennisetum purpureum* Schum.) was forage-harvested in autumn and spread under trees as mulch 10 cm deep in all treatments except Treatment 1 (bare ground).

From 1980 onwards, the dolomite application was reduced to 1 t ha^{-1} year^{-1} and gypsum to 2 t ha^{-1} year^{-1}, while 100 kg ha^{-1} of $MgSO_4$ was added to treatments receiving dolomite and gypsum. The actual nutrient levels applied in 1979 and 1981 are given in Table 1.

The following treatment contrasts were tested for significance in analyses of variance: FERT: unfertilized vs. fertilized treatments, i.e. 1, 2, 5 vs. 3, 4, 6, 7; HERBAGE: no fertilizer, bare ground vs. herbage, i.e. 1 vs. 2, 5; F0, KS vs. CC: no fertilizer, kikuyu sward vs. cover crop, i.e. 2 vs. 5; F+,KS vs. CC: fertilized, kikuyu sward vs. cover crop, i.e. 3, 4 vs. 6, 7; FKS, Cal vs. Urea: fertilized kikuyu sward, $Ca(NO_3)_2$ vs. urea, i.e. 3 vs. 4; FCC, Dol vs. Gyp: fertilized cover crop, dolomite vs. phosphogypsum, i.e. 6 vs. 7.

Soil sampling. – Soils were sampled prior to preparation of the trial site, then annually from 1974 to 1983, avoiding very wet conditions. Two disturbed samples, each of 400–500 g, were taken from test trees just beyond the drip-line. The surface layer (2–3 cm) containing roots and mulch was removed and the soil sampled to a depth of 15 cm.

Soil samples were immediately refrigerated until the commencement of analysis. The following chemical analyses were carried out: pH (1:2, w/v, soil:water), electrical conductivity (1:2, w/v, soil:water) and exchangeable cation concentrations (Bradley et al., 1983) and Bray no. 1 extractable phosphate (Bray and Kurtz, 1945).

At the conclusion of the trial, in February 1986, trenches were dug with a backhoe between the trial trees in each plot. Two cores of soil (73 mm diameter × 50 mm long) were taken horizontally at depths of 15, 30, 50 and 80 cm. Gravimetric water content and bulk density were determined using the methods of McIntyre and Loveday (1974) and air-filled porosity calculated according to McIntyre (1974) using a particle density of 2.7 Mg m^{-3}. Disturbed soil was taken from each depth for the determination of pH (1:5, w/v, soil: 0.01 M $CaCl_2$), electrical conductivity (1:5, w/v, soil:water) and exchangeable cation concentrations (Abbott, 1985).

Leaf sampling. – Leaf nutrient levels were determined for healthy trees and those affected by root rot. The leaf sampling procedure was similar to that used by Embleton et al. (1959) and Wutscher and Maxwell (1975). Leaves were washed, dried and ground by the methods of Leece (1976). Leaf nitrogen content was determined by an automated version of the semi-micro method of Havilah et al. (1977); sulphur determination was by indirect atomic absorption after barium precipitation (Rose, 1981); boron analysis was performed by a modification of the azomethine-H method of Gaines and Mitchell (1979); all other nutrients were determined by the methods of Leece et al. (1971).

Fruit and tree measurements. – Total fruit weight from each tree was measured from 1974 to 1983, while mean fruit size was estimated annually from a subsample of 50 per fruit tree. Tree girth was measured annually at a position 20 cm above the graft union after fruit harvest in May from 1974 to 1983. The data were analysed by a multivariate (repeated measurement) analysis of variance.

Tree health. – Trees were rated for tree health on a scale ranging from 0 (very healthy) to 10 (dead). Fruit size and yield from trees judged to be suffering from Phytophthora root rot were compared with fruit size and yield from healthy trees.

Phytophthora *isolation and behaviour in soil extracts.* – *Phytophthora cinnamomi* was isolated from soil and root samples either by the apple baiting technique (Campbell, 1949), by direct plating on one-quarter strength potato dextrose agar (PDA) containing penicillin and pimaricin (Broadbent and Baker, 1974) or by plating on HMI medium (Masago et al., 1977). *Phytophthora* behaviour in non-sterile soil leachates was assessed using the methods of Broadbent and Baker (1974).

Soil respiration studies. – Soil respiration studies were carried out on refrigerated samples by the methods of Smith (1976). The procedure developed by

Verstraete et al. (1983) was used to extract and determine microbial adenosine 5′-triphosphate (ATP) in soil.

RESULTS

Soil chemical analysis. - Soil pH in the top 15 cm was raised by applying dolomite in Treatments 3, 4 and 6 (Table 2), but pH decreased with increasing soil depth under these treatments (Table 3). The application of phosphogypsum had little effect on pH (Tables 2 and 3). Exchangeable aluminium levels at 0–15 cm were reduced to negligible values with the application of dolomite, but also appear to have been reduced, albeit to a lesser extent, with phosphogypsum application (Table 2).

Salinity levels (as indicated by electrical conductivity measurements) (Table 2) in the top 15 cm, from 1977 to 1980, were similar in Treatments 1–6. The higher level in Treatment 7 was probably due to the presence of undissolved gypsum in the soil. However by 1986 salinity levels had declined in all treatments (Table 3), showing the strongly leached nature of these soils.

Over the period 1977–1980, higher exchangeable Ca and Mg levels were detected at 0–15 cm in soils receiving the higher application rates of these elements (Table 2). Although large quantities of Ca were applied to soils in Treatments 3, 4, 6 and 7, exchangeable Ca levels remained low in 1976 and early 1977, increased sharply in late 1977, then declined slightly in 1980 (Fig. 3a). The low Ca levels correspond to years of higher than average rainfall (Fig. 1).

Values of the Ca/Mg ratio were decreased in Treatments 3 and 4 compared

TABLE 2

Mean pH (1:2 soil:water), electrical conductivity (1:2), Bray 1 P and exchangeable cation concentrations in the top 15 cm of soil over the period 1977-1980

Treatment	pH	Electrical conductivity (dS m^{-1})	Bray 1 P (mg kg^{-1})	Exchangeable cations (cmol(+) kg^{-1})					
				Ca	Mg	K	Na	Al	Ca/Mg
(1) BG	5.1	0.22	9.8	4.9	2.8	0.18	0.18	0.25	1.8
(2) KS	5.1	0.16	6.6	4.8	2.8	0.87	0.18	0.26	1.7
(3) KS+Dol+Cal	5.9	0.25	8.5	9.5	7.3	0.76	0.13	0.04	1.3
(4) KS+Dol+Urea	6.1	0.29	8.8	11.0	7.1	0.96	0.14	0.06	1.5
(5) CC	5.0	0.21	8.7	5.8	2.5	0.84	0.10	0.21	2.3
(6) CC+FM+Dol	6.4	0.29	26.0	14.8	6.7	1.26	0.11	0.00	2.2
(7) CC+FM+Gyp	5.3	0.44	35.6	15.7	0.9	0.68	0.89	0.15	17
Standard error of means	0.1	0.02	2.1	0.8	0.3	0.13	0.02	0.07	

TABLE 3

Mean pH (1:5 soil:0.01 M $CaCl_2$), electrical conductivity (1:5) and exchangeable cation concentrations of soil samples at different depths ($n=4$) taken in 1986

Treatment	pH				Electrical conductivity (dS m^{-1})				Exchangeable Ca (cmol(+) kg^{-1})				Exchangeable Mg (cmol(+) kg^{-1})				Exchangeable Ca : Mg			
	15 cm[1]	30 cm	50 cm	80 cm	15 cm	30 cm	50 cm	80 cm	15 cm	30 cm	50 cm	80 cm	15 cm	30 cm	50 cm	80 cm	15 cm	30 cm	50 cm	80 cm
(1) BG	4.6	4.7	4.8	4.9	0.15	0.10	0.06	0.08	4.4	3.3	1.8	1.4	1.4	1.4	1.0	0.6	3.1	2.4	1.8	2.3
(2) KS	4.6	4.8	4.9	5.0	0.13	0.09	0.08	0.09	3.5	2.1	1.5	1.5	1.5	1.3	1.1	0.7	2.3	1.6	1.4	2.1
(3) KS+Dol+Cal	5.6	5.2	5.1	4.9	0.10	0.10	0.06	0.07	6.0	2.9	2.0	1.8	3.9	2.8	1.7	0.7	1.5	1.0	1.2	2.6
(4) KS+Dol+Urea	5.6	5.2	5.2	5.0	0.15	0.14	0.08	0.06	7.8	3.3	3.0	2.1	4.1	2.7	2.0	0.9	1.9	1.2	1.5	2.3
(5) CC	4.8	5.0	5.2	5.2	0.15	0.12	0.08	0.07	5.0	3.9	2.5	2.3	1.9	1.7	1.0	0.6	2.6	2.3	2.5	3.8
(6) CC+FM+Dol	6.0	5.4	5.3	5.4	0.21	0.16	0.08	0.05	15.0	3.8	2.5	1.3	5.9	2.2	1.5	0.8	2.5	1.7	1.7	1.6
(7) CC+FM+Gyp	4.9	4.9	5.0	4.8	0.09	0.10	0.09	0.09	9.3	6.3	6.4	6.0	1.0	0.8	0.9	1.3	9.3	7.9	7.1	4.6
Standard error of means	0.1				0.02				1.3				0.4				1.1			

[1] Soil depth.

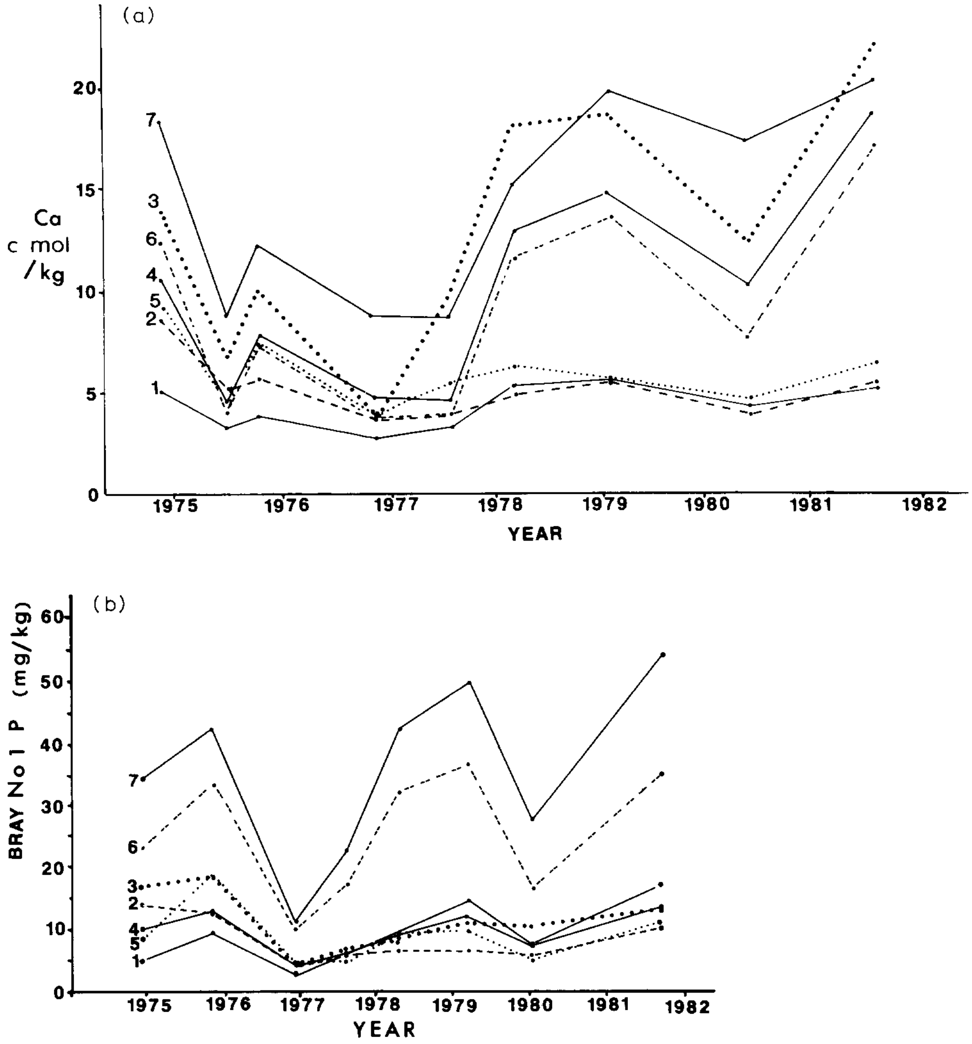

Fig. 3. The effect of rainfall (> 250 mm) on exchangeable calcium (a) and phosphorus (b) in the topsoil (0-15 cm) from 1975 to 1982 in Treatments 1-7.

to Treatment 1, but the value in Treatment 7 increased markedly as a result of the application of large amounts of Ca and small quantities of Mg (Tables 1 and 2). Despite this very high Ca/Mg ratio level in Treatment 7, Mg uptake by the trees, although lower than in the other treatments, was sufficient to prevent Mg deficiency (Table 4).

By 1986 exchangeable Ca and Mg levels in the top 15 cm had generally declined but were still higher in Treatments 3 and 4, and particularly 6, than in Treatment 1 (Table 3). Gypsum application resulted in increased exchange-

TABLE 4

Mean leaf nutrient levels in Treatments 1-7 from 1979 to 1982

Treatment	N (dag kg^{-1})	P (dag kg^{-1})	K (dag kg^{-1})	Ca (dag kg^{-1})	Mg (dag kg^{-1})	S (dag kg^{-1})	Cl (dag kg^{-1})	B (mg kg^{-1})	Mn (mg kg^{-1})
(1) BG	2.035	0.120	0.805	1.147	0.492	0.186	0.093	24.3	485
(2) KS	2.130	0.135	0.958	1.019	0.496	0.210	0.219	24.5	620
(3) KS+Dol+Cal	2.384	0.139	0.763	1.016	0.591	0.202	0.121	18.6	201
(4) KS+Dol+Urea	2.281	0.140	0.812	1.043	0.578	0.201	0.138	19.9	213
(5) CC	2.219	0.125	0.766	1.119	0.483	0.190	0.137	20.2	367
(6) CC+FM+Dol	2.367	0.139	0.779	1.285	0.599	0.208	0.094	19.1	131
(7) CC+FM+Gyp	2.332	0.134	0.803	1.445	0.426	0.223	0.098	20.1	262
Standard error of means	0.049	0.003	0.024	0.051	0.016	0.003	0.011	0.8	28
No. sampled	76	76	77	77	77	76	60	68	77

Treatment contrast	Significance of treatment contrasts ($P < 0.05$)								
	N	P	K	Ca	Mg	S	Cl	B	Mn
FERT	*	*	-	-	*	*	*	*	*
HERBAGE	-	-	-	-	-	*	*	-	-
F0, KS vs. CC	-	-	*	-	-	*	*	*	*
F+, KS vs. CC	-	-	-	*	*	*	*	-	-
FKS, Cal vs. Urea	-	-	-	-	-	*	*	*	*
FCC, Dol vs. Gyp	-	-	-	*	*	*	-	-	*

able Ca levels to at least 80 cm. The Ca/Mg ratio in the top 15 cm of Treatment 7 had declined since 1980 due to decreasing applications of fertilizer containing Ca but was still higher than is desirable to avoid the possibility of Mg deficiency.

Soils in Treatments 6 and 7 receiving fowl manure showed significantly ($P<0.001$) higher Bray no. 1 phosphate levels than Treatments 1–5 (Table 2). Phosphate levels in Treatment 7 were significantly higher ($P<0.05$) than in Treatment 6 due to the phosphate content of the gypsum (Table 1). Phosphate levels were depressed in years of high rainfall (Fig. 3b).

Leaf analysis. – In the period 1971–1982 the gypsum treatment produced the highest mean leaf Ca and the lowest mean leaf Mg levels (Table 4). The higher Ca levels at depth in soils of Treatment 7 may be responsible for the higher leaf Ca levels.

Higher soil levels of P in Treatments 6 and 7 were not reflected in higher leaf levels (Table 4) and leaf nitrogen levels were not greatly affected by the fowl-manure applications. The large increases in the supply of N, P and K did not give any significant increases in leaf concentrations in these elements.

A comparison of leaf analyses for healthy and root rot-affected trees, over all treatments, showed a dramatic reduction in all leaf nutrient levels in the diseased trees and this effect was apparent from the first appearance of symptoms (Table 5).

TABLE 5

Mean leaf nutrient levels in 420 samples taken from healthy trees and 29 samples from diseased trees over the period 1977–1982

Nutrient	Healthy	Diseased	Standard deviation	Statistical significance ($P<0.05$)
($\mathrm{dag\ kg^{-1}}$)				
N	2.25	1.37	0.33	*
P	0.13	0.08	0.03	–
K	0.81	0.50	0.16	*
Ca	1.15	0.67	0.34	*
Mg	0.52	0.48	0.12	–
S	0.20	nd	0.03	–
Cl	0.055	nd	0.075	–
Na	0.026	0.016	0.023	*
($\mathrm{mg\ kg^{-1}}$)				
B	18.7	15.9	8.2	*
Mn	326	171	234	–
Fe	114	62	191	–
Cu	33	10	30	*
Zn	46	27	29	*

nd = not determined.

TABLE 6

Mean bulk density, gravimetric water content and air-filled porosity of soil cores ($n=8$) taken in 1986

Treatment	Bulk density ($\mathrm{Mg\ m^{-3}}$)				Gravimetric water content ($\mathrm{kg\ kg^{-1}}$)				Air-filled porosity ($\mathrm{m^3\ m^{-3}}$)			
	15 cm[1]	30 cm	50 cm	80 cm	15 cm	30 cm	50 cm	80 cm	15 cm	30 cm	50 cm	80 cm
(1) BG	0.93	0.95	1.08	1.10	0.48	0.48	0.40	0.39	0.21	0.20	0.17	0.18
(2) KS	0.92	0.97	1.00	1.11	0.50	0.44	0.43	0.39	0.21	0.22	0.21	0.16
(3) KS+Dol+Cal	0.92	0.98	1.08	1.11	0.45	0.41	0.37	0.35	0.26	0.25	0.20	0.20
(4) KS+Dol+Urea	0.91	1.00	1.02	1.10	0.46	0.42	0.39	0.38	0.25	0.22	0.22	0.18
(5) CC	0.97	1.01	1.09	1.12	0.43	0.42	0.39	0.40	0.23	0.21	0.18	0.15
(6) CC+FM+Dol	0.94	1.02	1.15	1.25	0.47	0.40	0.36	0.34	0.22	0.22	0.16	0.12
(7) CC+FM+Gyp	0.96	1.10	1.12	1.20	0.43	0.38	0.36	0.40	0.24	0.18	0.20	0.09

[1] Soil depth.

Soil physical analysis. – The bulk density values of these krasnozem soils at the final sampling in 1986 (Table 6) generally increased with depth, a function of decreasing organic matter content (not shown) and, in some profiles, increasing rock content (Fig. 2). Gravimetric water content values were low in terms of plant production in that 0.25–0.30 kg $\mathrm{kg^{-1}}$ (the 1.5 MPa water content of these soils) is unavailable to plants.

The air-filled porosity values (Table 6) reflect the highly-structured, relatively dry nature of the soils at sampling. The mean values were generally greater than 0.10 $\mathrm{m^3\ m^{-3}}$, the critical level for satisfactory root respiration. However, there were some low individual values (less than 0.10 $\mathrm{m^3\ m^{-3}}$) at depths of 50 and 80 cm (not shown), corresponding to high bulk density values. More instances of values less than 0.10 $\mathrm{m^3\ m^{-3}}$ would have been observed if the soils had been wetter at the time of sampling. For a bulk density of 1.20 $\mathrm{Mg\ m^{-3}}$ the air-filled porosity is less than 0.10 $\mathrm{m^3\ m^{-3}}$ if the gravimetric water content exceeds 0.38 kg $\mathrm{kg^{-1}}$.

Considering that these soils have "field capacity" (10 kPa water content) values of 0.45–0.60 kg $\mathrm{kg^{-1}}$, it seems likely that wherever the bulk density exceeds 1.20 $\mathrm{Mg\ m^{-3}}$ air-filled porosity values will very often be less than 0.10 $\mathrm{m^3\ m^{-3}}$.

Soil respiration and microbial biomass. – Soil respiration studies using gas chromatography were carried out in 1976, 1979 and 1980 and showed no gross differences to reflect the management treatments applied. The soils under all treatments were low in ethylene and had low respiration rates. ATP determinations were carried out on soils in 1982 (Table 7) and 1983 and were higher in fertilized treatments than in treatments where no fertilizer was applied. In fertilized soils under a cover crop, the addition of dolomite produced higher ATP levels than did gypsum. Results were highly variable. There was no re-

TABLE 7

Mean values, standard errors of means and significant effects ($P<0.05$) for adenosine triphosphate (ATP) (mg g^{-1} dry wt. soil) in soils collected in 1982

Treatment	ATP
(1) BG	201
(2) KS	242
(3) KS+Dol+Cal	273
(4) KS+Dol+Urea	383
(5) CC	314
(6) CC+FM+Dol	474
(7) CC+FM+Gyp	290
Standard error of means	51
Effects which differ ($P<0.05$)	
F0	252
F+	355
FCC, Dol	474
FCC, Gyp	290

lationship between ATP value and the presence or absence of Phytophthora root rot.

Distribution of P. cinnamomi *in trial site.* – *Phytophthora cinnamomi* (Rands) was first isolated from soil and roots under a buffer tree and under a nearby trial tree, both suffering from root rot, in Block 4 in 1977. By 1982 the fungus had been detected throughout the trial site.

Phytophthora *behaviour in non-sterile soil leachates.* – In the first 2 years of the trial, sporangium production was greater and mycelial lysis was less in leachates of soils from the bare ground treatment. From 1979 to 1983 there were no effects of any treatment on behaviour of *P. cinnamomi* in soil leachates.

Tree health. – In the early years of the trial all trees were healthy. In 1977 2 trees in Block 4 started to decline owing to Phytophthora root rot. In 1981, 4 trial trees were severely affected by root rot in Treatments 1, 2 and 5. By 1982, 13 of the 56 trial trees were affected by Phytophthora root rot (Fig. 2). There was no effect of treatment on the incidence of Phytophthora root rot.

Tree girth, fruit size and yield. – Trees receiving calcareous and nitrogenous amendments had girths which increased faster than those of unfertilized trees over the period 1974–1983 (Fig. 4). For trees grown with cover crop and fowl manure, those which received dolomite grew faster than those given phosphogypsum from 1977 onward. There was no significant effect of form of nitrogen-

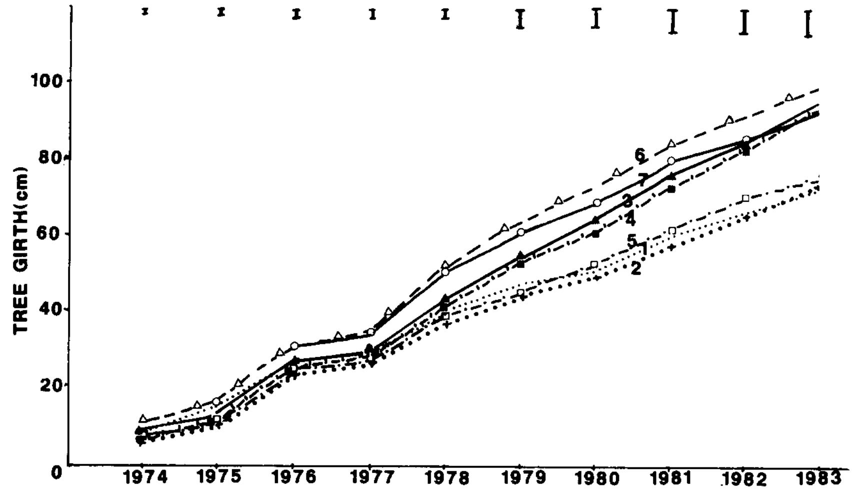

Fig. 4. The effect of Treatments 1-7 on tree girth (cm) from 1974 to 1983. Bars indicate standard errors of means.

TABLE 8

Mean values and standard errors of means for health rating (0=healthy, 10=dead), yield and fruit weight for healthy and diseased trees in 1982, 1983 and 1984 (6 trees group^{-1})

Year	Health (0-10)		Yield (kg tree^{-1})		Fruit weight (g)	
	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
1982	1.1	3.7	151	63	307	246
1983	0.1	6.3	56	24	312	224
1984	0.4	6.0	111	16	307	187
Standard error of means	1.0	1.0	22	22	34	34

ous amendment, Ca(NO$_3$)$_2$ or ureaformaldehyde on the girth of trees grown with a kikuyu sward from 1977 to 1980.

There were no significant differences between average fruit weights for different treatments. Trees visually affected by Phytophthora root rot yielded less and had smaller fruit than healthy trees in all treatments (Table 8).

Trees receiving additional fertilizer amendments yielded significantly more fruit than trees receiving only basal fertilizer applications over the period 1977–1980 (Fig. 5). From 1981 there were no significant differences between treatments. Trees yielded heavily every second year under all treatments except bare ground. Yield of trees in the bare-ground treatment improved relative to

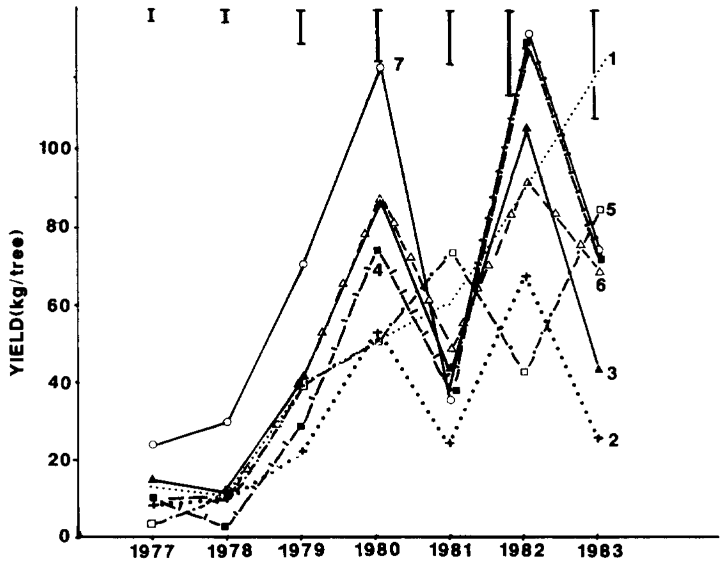

Fig. 5. The effect of soil management treatments on yield (kg tree^{-1}) from 1977 to 1983 (healthy trees only). Bars indicate standard errors of means.

yield in the kikuyu and cover-crop treatments over the period 1977–1980. In the cover-crop and fowl-manure treatments, trees receiving phosphogypsum significantly outyielded trees fertilized with dolomite.

DISCUSSION

Broadbent and Baker (1974, 1975) considered that high cation exchange capacity, high organic matter and intense microbial activity in the soil contributed to the suppression of Phytophthora root rot. This trial achieved high cation exchange levels, but fell short of the desired levels of organic matter and microbial activity. Soil microbial biomass, as indicated by ATP determinations, was higher in fertilized than unfertilized soils, with dolomite giving higher ATP levels than gypsum in soils under a fertilized cover crop.

Phytophthora cinnamomi could not be isolated from the trial site for the first few years. Once introduced, *P. cinnamomi* spread throughout the site within 5 years and resulted in 25% loss of trial trees. There were no differences in behaviour of *P. cinnamomi* in non-sterile soil leachates in response to treatment.

Several studies have suggested that calcium may have a positive effect on control of Phytophthora root rot (Zentmyer and Lewis, 1975), especially in areas of low oxygen supply (Chapman, 1965). This may be due to hosts grown in the presence of high levels of Ca^{2+} being more resistant to infection or tissue colonization (Lee, 1979), a reduction in the rate of spread of *P. cinnamomi* in host tissue (Bellamy et al., 1971) or to increased development of ectomycorrhizal fungi (Boughton et al., 1978). However, like Halsall (1980) we could find no positive effects on root rot development or behaviour of *P. cinnamomi* that could be directly attributed to the influence of higher Ca levels. Nor in these highly structured soils did higher Ca levels have an effect on bulk density or air-filled porosity.

Trees developed Phytophthora root rot first in a section of the trial where there was bedrock in the top 80 cm of the soil profile, but later root rot developed in trees growing mainly in the north-eastern corner (Block 2), the lowest part of the trial area (Fig. 2). Except for Treatments 4 and 5 in Block 2, root rot development corresponded also to bedrock or weathering rock in the top 80 cm. Some diseased trees also occurred in the higher Blocks 4 and 1 where there was bedrock, weathering rock or high bulk density in the top 80 cm. Only the highest block (No. 3) was completely free of root rot (Fig. 2).

These observations suggest that the main factor affecting the incidence and severity of Phytophthora root rot in this trial was soil drainage, as determined by the presence of bedrock, weathering rock or high bulk density in the top 80 cm, and by topography. This is supported by Wolstenholme and Le Roux (1974) who state that the primary requirement of an avocado soil is fast internal drainage so that excess water draining through the soil is not impeded or stopped within at least the top 1.5–2 m; Pegg and Forsberg (1982) suggest 3 m. A well-drained topsoil is not sufficient; an impermeable clay subsoil, hardpan or rock layer near the surface can cause poor drainage and perched water tables during periods of high rainfall (Wolstenholme and Le Roux, 1974). Pegg and Forsberg (1982) state that it is almost impossible to make poorly drained avocado soil productive, even with frequent applications of fungicides and strict attention to management practices such as cover cropping. Similarly, management treatments did not reduce the incidence of root rot in poorly-drained sections of this trial.

The mean yields over all treatments recorded in this trial are 131% higher than those reported by Embleton and Jones (1972) for trees of comparable ages and several times higher than those recorded by Aziz et al. (1975) in Egypt, who also used 'Fuerte' on 'Fuerte' rootstock. In California most varieties, and particularly 'Fuerte', exhibit biennial bearing (Embleton and Jones, 1972). The data from this trial indicate that the climate is equable (Fig. 1), which considerably reduces the biennial bearing tendencies.

Trees receiving phosphogypsum produced more fruit from 1977 to 1980 than trees receiving dolomite, although trees given dolomite grew faster. Inputs of fowl manure and cover crop were the same in both treatments. Besides the higher yields, the smaller stature of trees in the phosphogypsum treatment is desirable in avocados, as dwarfing rootstocks are not commercially available.

Phytophthora root rot affected the health rating and yield of trees, and the reduced fruit size (approx. 200 g fruit^{-1}) made them unacceptable for the Australian market. The reduced levels of N, P, K and Ca in leaves of trees affected by Phytophthora root rot coincides with reduction in fruit size and yield. Whiley et al. (1987) found the concentrations of nitrogen, phosphorus, boron and sulphur were lower and chloride accumulation was higher in leaves of avocado trees severely affected by root rot compared with leaves from trees treated with fungicides.

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