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Effects of Intercropping Systems on Surface Processes in an Acid Ultisol 2. Changes in Soil Chemical Properties and Their Influence on Crop Performance

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The chemical changes in an acid Ultisol under intercropping, were monitored over thirty-three months. The systems of intercropping under immature rubber were designed on the basis of conservation-oriented surface vegetative cover. The lower input systems include interrows under a) naturals, and b) legumes; while the intercropped plots represent the high input treatments comprising c) peanut and corn rotation, d) pineapple, and e) combination of peanut–corn and pineapple. The use of fertilisers and the corrective input of lime influence the soil fertility dynamics. Towards the later croppings, the pH declined in all interrow systems, with a marked decrease in the highest input plots. The intercropped treatments showed significant residual amounts of phosphorus, calcium and magnesium. Over several croppings, the effective cation exchange capacity remains high and the soils have low aluminium saturation. Intercropping has an overall beneficial effect on growth of Hevea *due to the combined effect of added fertilisers and lime.*

It is imperative that due to the low inherent fertility of tropical soils, fertilisers form an important component of the agro-management inputs. The use of mixtures and compound fertilisers for optimum growth and productivity of *Hevea* is a well established practice. Continued application of fertilisers affected changes in the soil nutrient status[1]. In several field experiments on acid Ultisols and Oxisols, Pushparajah *et al.*[2] observed a reduction in pH and exchangeable cations as a result of the long-term use of ammonium sulphate. On the other hand, the application of rock phosphate led to build-up of phosphate and calcium levels. The mobility and accumulation of phosphate and calcium were further confirmed from field trials on Ultisols[3]. The residual phosphate in particular had a beneficial effect on growth of *Hevea* and legumes[3,4].

The practice of growing annual crops under rubber, commonly referred to as intercropping, involves broadcast application of lime and fertilisers. Depending on the frequency of croppings, it can be expected that dynamic changes in the soil nutrient status will occur throughout the cropping period due to the large amount of fertilisers applied. In a study on continuous cropping of Amazon soils freshly cleared from jungle, Sanchez *et al.*[5] developed a fertiliser programme based on soil nutrient dynamics. The favourable soil chemical properties that resulted in this study were found to support an economically viable continuous production system.

The chemical properties that are considered favourable for food crops generally include optimum pH levels, large reserves of bases and low levels of aluminium saturation, *i.e.* properties that are found wanting in acid tropical soils[6]. In a previous study[7], indications of the physical fragility of the soils under intercropping were detected. This study focusses on the changes in the soil nutrient status and their effects on productivity of the intercropping systems.

MATERIALS AND METHOD

There are five treatments arranged in a randomised complete block design, with each treatment being replicated four times. The low input treatments allow vegetative ground coverage in interrows throughout the duration of the field trial and consist of a) naturals (grasses and weeds), and b) leguminous covers; while the intercropped plots represent the high input treatments comprising c) rotation of peanut and corn, d) hedgerows of pineapple, and e) combination of peanut–corn and pineapple.

Before planting, lime was incorporated at the rate of 2 tonnes/ha in the intercropped plots. *Hevea* (clone RRIM 712) was planted in February 1989 at a planting distance of 8.5 × 2.4 m. Peanut (*Arachis hypogea*) was planted at a distance of 30 × 10 cm at a seeding rate of 110 kg/ha, and corn (*Zea mays*) was planted at 60 × 30 cm with a seeding rate of 10 kg/ha. During the first year, the crop rotation was peanut followed by corn and a second crop of peanut. In the second and third years of the field trial, the cropping sequence was peanut followed by corn. All the crops including the leguminous covers, received compound N, P, K and Mg fertilisers. The nutrients each crop received and the total inputs of nutrients for all croppings are shown in *Table 1*. The total fertiliser inputs were for four crops of peanut and three crops of corn, and three years of routine fertiliser dressings in the case of *Hevea*. The routine fertiliser dressings for the legumes, rubber, pineapple and papaya refer to the scheduled fertiliser programme which the crops received over its growth cycle. Papaya was the initial medium-term crop but due to severe virus infection, it was replaced by pineapple. It can be observed that lime, besides being the basal input for the intercrops, is also an important source of nutrient for papaya. The base input of lime contributed to 600 kg/ha of CaO and 400 kg/ha of MgO. Corrective liming at the rate of 1 tonne/ha was carried out before the start of the second cropping cycle. Since lime was applied at the onset of the cropping cycle, the total CaO and MgO received by the respective intercrops, were not computed. The total nutrients received per treatment are shown in *Table 2*.

Soil samples were obtained from all the plots before establishing the trial and at every harvest. The samplings coincided with 94, 208, 337, 515, 664, 859 and 1007 days after establishing rubber. For each plot, a composite sample consisting of ten randomly taken soil cores was air-dried and ground to pass through a 2 mm sieve. The soils were then analysed for pH, organic carbon, total N, available P, exchangeable bases (K, Ca, Mg), cation-exchange capacity (CEC) and exchangeable Al. The soil analysis was carried out according to the methods described earlier[8].

RESULTS AND DISCUSSION

Soil Acidity Parameters

The soil pH levels after the seventh crop indicate a decrease from the pre-cultivated values in all the intercropping systems except for the plots with corn and peanut rotation (*Figure 1*). The highest levels were attained in the high input systems with corn and peanut as the main intercrops. Over seven croppings, the

TABLE 1. FERTILISER INPUTS FOR SPECIFIC CROPS

Crop	Nutrients per crop (kg/ha)					Total nutrients received (kg/ha)				
	N	P_2O_5	K_2O	CaO	MgO	N	P_2O_5	K_2O	CaO	MgO
Legume	- - - - - - - - - - Routine dressing - - - - - - - - - -					7	217	10	300	1
Peanut	48	48	68	–	8	192	192	272	–	32
Corn	78	78	98	–	8	234	234	294	–	24
Pineapple	- - - - - - - - - - Routine dressing - - - - - - - - - -					372	263	570	–	73
Rubber	- - - - - - - - - - Routine dressing - - - - - - - - - -					221	221	88	–	58
Papaya	- - - - - - - - - - Routine dressing - - - - - - - - - -					42	142	42	878	490

TABLE 2 TOTAL FERTILISER INPUTS PER INTERROW TREATMENT

Interrow treatment	Total nutrients received (kg/ha)				
	N	P_2O_5	K_2O	CaO	MgO
Naturals	–	–	–	–	–
Legumes	7	217	10	300	1
Corn/peanut	426	426	566	900	656
Pineapple	414	405	612	878	563
Pineapple – corn/peanut	613	676	859	1 328	863

highest input system of the pineapple hedgerows in combination with corn and peanut, shows the highest pH levels. The pH in this plot during the third cropping is 5.7. This is attributed to the rather high input of dolomitic limestone when papaya was the medium-term crop (*Table 1*). In addition, a corrective liming rate of 1 tonne/ha was carried out before the fourth cropping in the plots with the short-term crops. The maximum pH levels were generally recorded during the third and fourth croppings, coinciding with the low rainfall months during the first half of 1990. The decline in pH is due to the combined factors of increasing rainfall regime and the continued use of sulphate-based nitrogen fertilisers. Overall, the response to liming is evident in the intercropped plots demonstrating the weak buffering capacity of Rengam series. The most dramatic decline in pH occurred in the highest input interrow system. In the case of the cleanly-cultivated pineapple plots, the final pH is close to the values recorded in the non-intercropped plots.

Since exchangeable aluminium is pH-dependent[9], the trend of aluminium levels is opposite to that of soil pH. It is evident that exchangeable aluminium increased after the fourth crop, and the lowest levels were recorded in the treatments with corn and peanut rotation. The aluminium contents for the plots with naturals and legumes were almost similar. The data for the last three croppings indicated the acidity regained in the pineapple plots to a level closely related to the non-intercropped systems. For the highest-input treatment, the aluminium contents during the first and last croppings were 20% and 49% respectively of that attained in the plots with naturals. It can be observed that the plots with cleanly-cultivated medium-term crops (pineapple) maintain high levels of aluminium, except during the fourth crop as a result of minimal leaching during the growth period. For the acidity parameters, significant differences among treatments were detected during the early croppings and the last two croppings.

Nitrogen and Phosphorus

Minor differences were detected for total soil nitrogen throughout the cropping cycle (*Figure 2*.) During the early phase of cropping, the intercropped plots showed relatively higher nitrogen content than the soils under naturals and legumes. The nature of the crops and their associated use of inorganic fertilisers were the main reasons for this observation. All the treatments indicated N peaks after the fourth crop. The increased rate of mineralisation is possibly due to the higher soil moisture content as a result of the onset of rain after a period of drought[10]. With the exception of the highest input system, the legume plots had higher N content than other treatments, with the higher N levels presumably attributed to its nitrogen fixation capacity. All the plots showed a gradual decline with further croppings, with the sole pineapple plots showing the lowest mineralisation rate and legume plots, exhibiting the least rate of decline.

. The available phosphorus indicated an increasing trend in all treatments particularly during the initial three croppings (*Figure 2*); and their peaks were attained at the third crop.

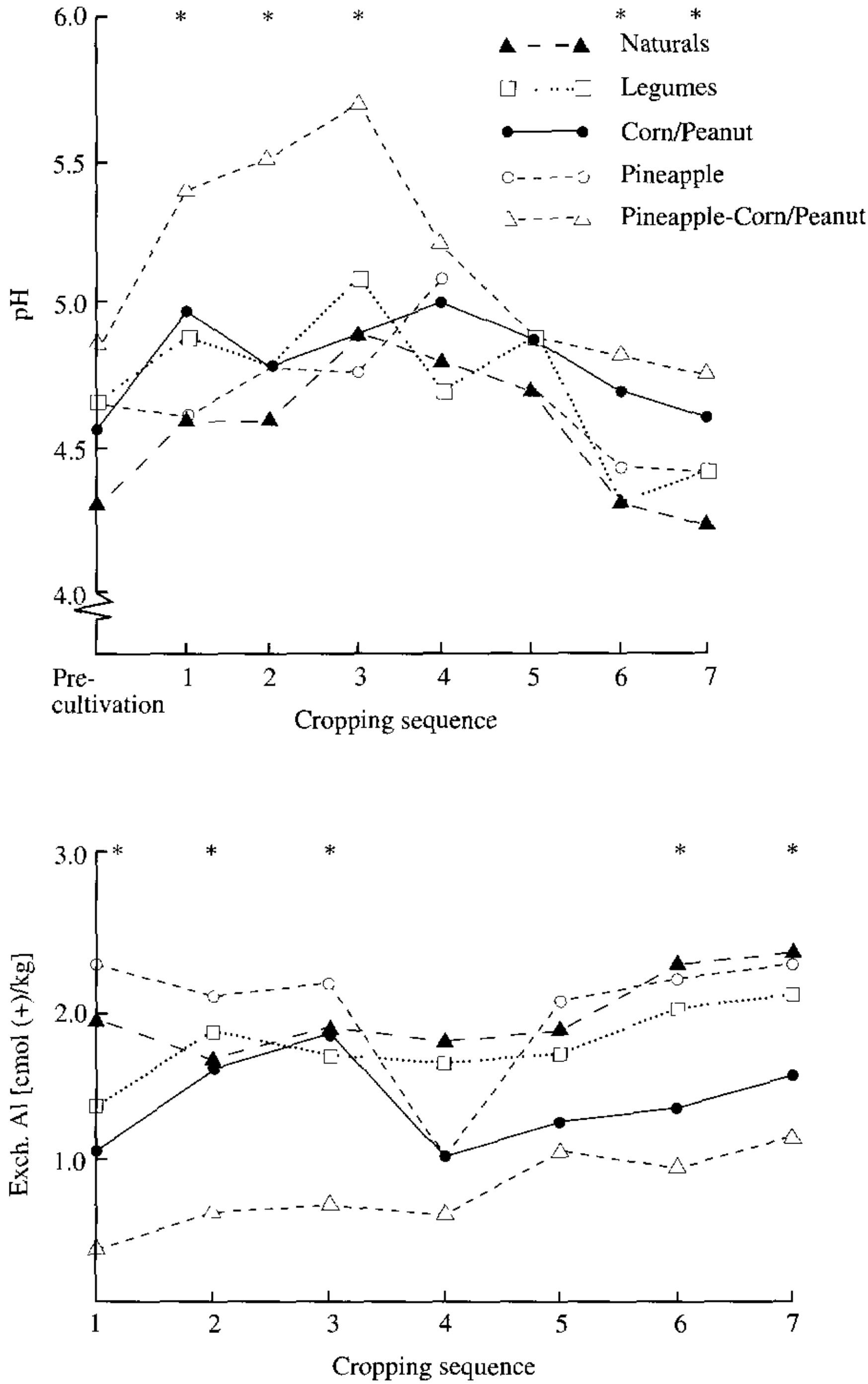

Figure 1. Changes in pH and exchangeable Al of surface soils (0–15 cm) with seven croppings. The asterisks indicate significant differences between the highest input system and one or more of the other systems.

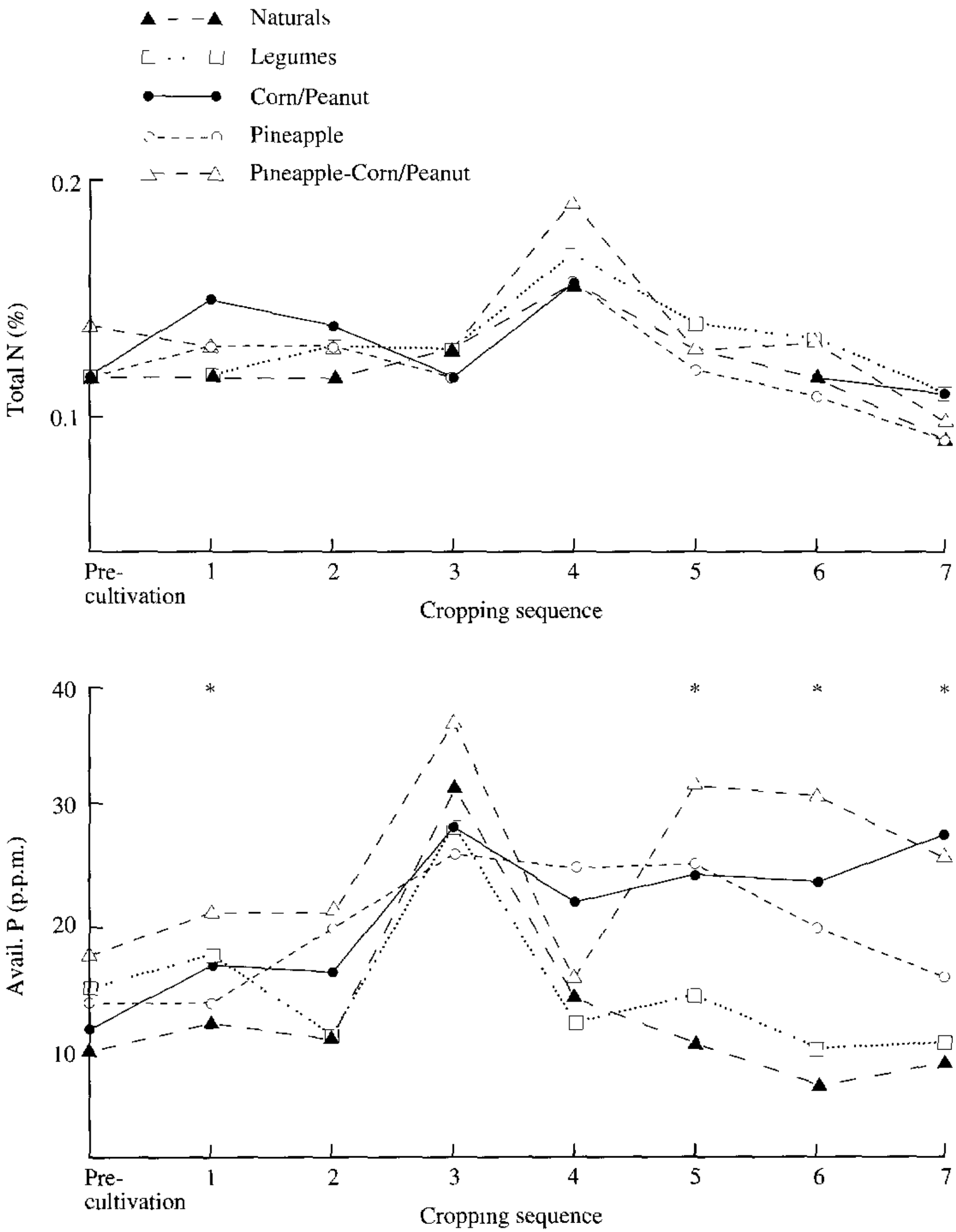

Figure 2. Changes in total N and available P of surface soils (0–15 cm) with seven croppings. The asterisks indicate significant differences between the highest input system and one or more of the other systems.

The maxima coincided with the period of low solubility during prolonged drought. Initially, the soils under legume showed high amounts of P and this can be attributed to the high amounts of phosphate rock used for its early establishment (*Table 1*). After the third crop, the non-intercropped plots exhibited a sharp decline in phosphorus and the final analysis indicated values close to the pre-cultivated levels. However, the high input treatments maintained high levels of residual P. The pattern of P content correspondingly reflected the amount of P_2O_5 broadcasted: 426, 405 and 676 kg/ha for corn/peanut, pineapple, pineapple – corn/peanut plots respectively. Significant differences among treatments were recorded especially during the later croppings.

Exchangeable Bases

Exchangeable potassium generally exhibits a gradual declining trend (*Figure 3*). High levels of potassium were attained in the highest input plots (pineapple – corn/peanut). The high mobility of potassium was indicated by the absence of distinct peaks apparent in the case of phosphorus. High K inputs for the intercropped plots resulted in high levels of soil potassium. Significant differences were detected during most of the croppings. The soils under naturals maintained almost constant K levels while in the legume plots, exhaustion of the K reserves was reflected in the sharper declining trend.

The contents of exchangeable calcium and magnesium are basically governed by the amount of dolomitic limestone incorporated. This explains the higher levels of the bivalent nutrients in the soils under the intercropping systems than in the soils under legumes and naturals (*Figure 3*). Among the intercropped treatments, the sole pineapple plots regained acidity earlier than the corn/peanut plots as shown by the sharper decline in the Ca and Mg contents. This phenomenon was also shown earlier by the decline of pH (*Figure 1*) such that the plots acquired acidity levels similar to the non-intercropped plots during the seventh cropping. This can be attributed to the leaching of Ca and Mg ions by rain during the early phase of pineapple establishment. During the final cropping, the highest input system (pineapple – corn/peanut) had the highest amount of residual Ca and Mg. The differences among the treatments were consistently significant throughout the cropping period.

Effective Cation-exchange Capacity, Al and (Ca + Mg) Saturation

The effective cation-exchange capacity (ECEC) which is the summation of exchangeable cations (Ca, Mg, K and Al) reflects the amount of total inputs in every treatment. Hence, the intercropped plots generally had higher ECEC values than the plots under legumes and naturals (*Figure 4*). In the treatment where corn and peanut were grown in rotation, the low amount of aluminium depressed the ECEC during the seventh crop. For this treatment, the tendency to remain at lower acidity levels was also shown previously in *Figure 1*. Overall, the high ECEC during the final cropping was an indication of high aluminium content (naturals and pineapple) and high Ca and Mg values (pineapple – corn/peanut).

To check the dominance of Al or Ca and Mg in the exchange complex, the relative percent saturation of the ECEC was determined (*Figure 4*). The pattern of Al saturation was inversely related to the Ca and Mg saturation throughout the field trial. It is apparent that the actively-managed interrows generally indicated the highest levels of Ca and Mg, corresponding to the lowest levels of Al saturation. The sole pineapple plots achieved acid conditions comparable to the soils under naturals and legumes. Considering the precultivated Al saturation of 87%, liming managed to neutralise the Al levels by 53% to 75% for the plots with corn and peanut rotation. The legume plots had relatively lower Al saturation than the soils under naturals, which can be attributed to the initial high inputs of rock phosphate in the former. The trend of cation saturation clearly indicates the rate of regaining acidity as a result of different management inputs and consequent surface processes. The slight decline in Ca and Mg levels for the highest input plot also indicates the effective-

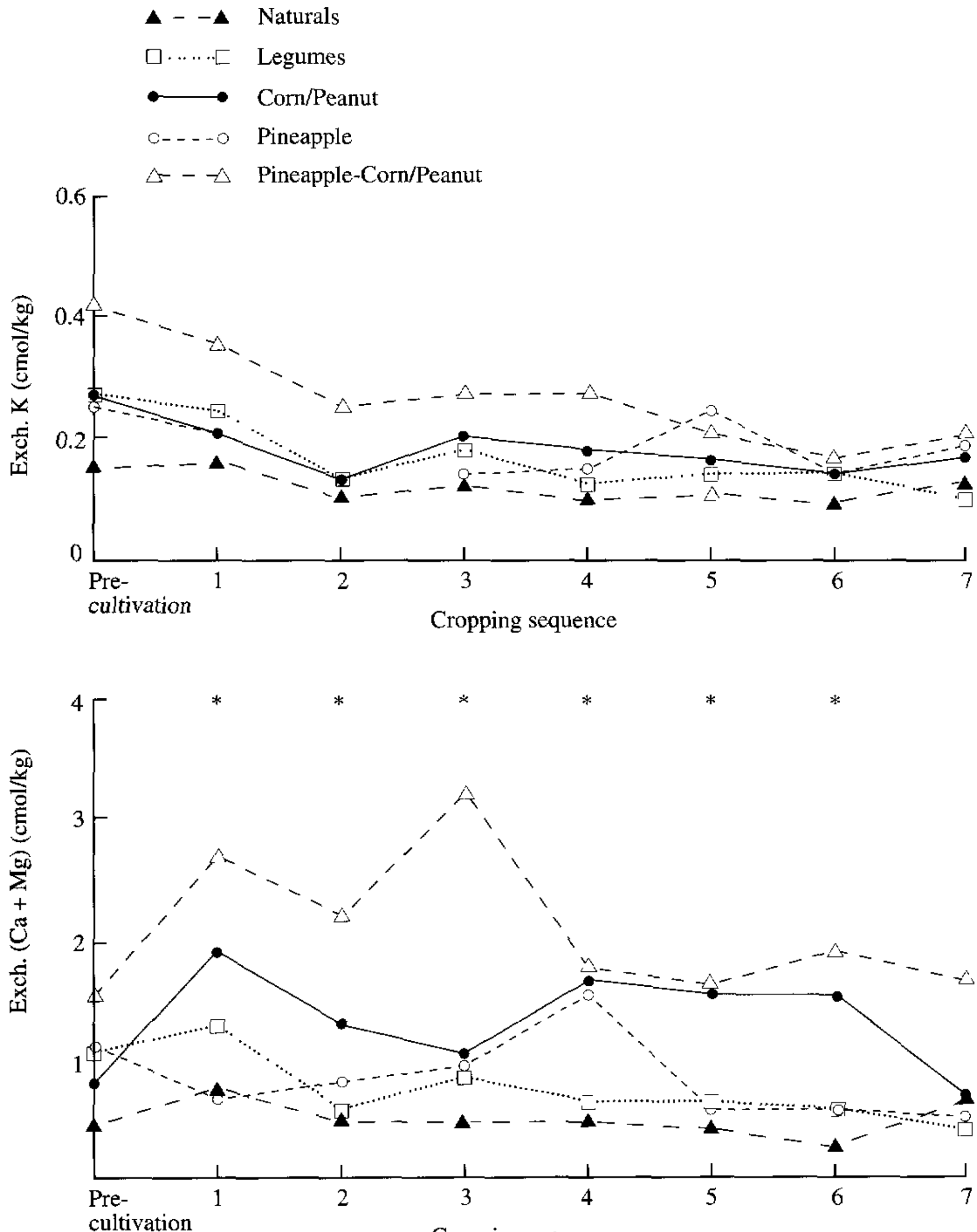

Figure 3. Changes in exchangeable K and (Ca + Mg) of surface soils (0–15 cm) with seven croppings. The asterisks indicate significant differences between the highest input system and or more of the other systems.

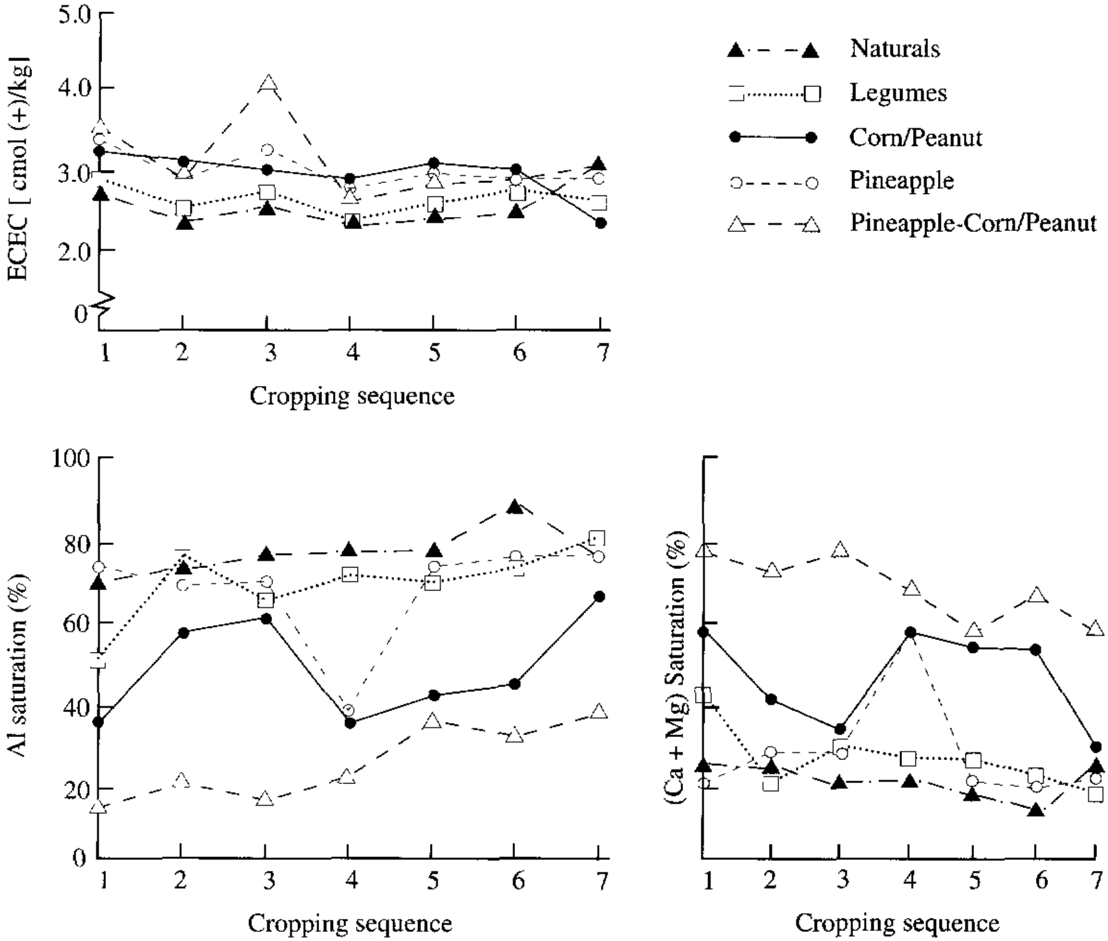

Figure 4. Changes in ECEC, Al and (Ca + Mg) saturation of ECEC over seven croppings.

ness of the cropping system to maintain high residual levels, which is of importance for consideration in planning conservation-oriented interrow systems under rubber.

Depth Distribution of Phosphorus, Calcium, Magnesium and Potassium

The variation in the content of P, Ca, Mg and K with depth is shown in *Table 3*. In the case of available P, the non-intercropped treatments indicated depletion after the seventh crop. For the legume plots, even though phosphate rock was applied initially, the actively-growing legume creepers with high demand for P, tended to exhaust the nutrient. The build-up of P, a relatively immobile nutrient, was distinct in the intercropped plots, and the highest content occurred in the surface 0–15 cm. The build-up was apparent up to a depth of 60 cm, particularly in the plots with pineapple, and those with a combination of

TABLE 3 DEPTH DISTRIBUTION OF PHOSPHORUS, CALCIUM AND MAGNESIUM AND POTASSIUM AT TWO SAMPLING PERIODS

Interrow treatment	Sampling time	Avail P (p p m)				Exch (Ca + Mg) [cmol(+)/kg]				Exch K [cmol(+)/kg]			
		0–15 cm	15–30 cm	30–45 cm	45–60 cm	0–15 cm	15–30 cm	30–45 cm	45–60 cm	0–15 cm	15–30 cm	30–45 cm	45–60 cm
Naturals	Pre-cult	10	7	6	6	0.42	0.21	0.09	0.19	0.16	0.11	0.05	0.10
	33 months	6	5	6	5	0.25	0.13	0.15	0.14	0.09	0.05	0.06	0.05
	t value	3.38*	2.53*	1.00	1.48	2.13(P<0.1)	1.18	2.47*	0.53	5.23**	3.13*	0.19	0.92
Legumes	Pre cult	15	9	7	7	0.95	0.24	0.16	0.17	0.27	0.13	0.07	0.06
	33 months	9	7	7	6	0.56	0.28	0.37	0.38	0.15	0.08	0.08	0.09
	t value	*1.46*	*1.89*	*0.14*	*0.56*	*0.77*	*0.48*	*0.90*	*1.06*	*1.23*	*1.59*	*0.24*	*0.77*
Corn/peanut	Pre-cult	12	8	7	7	0.71	0.28	0.14	0.16	0.27	0.15	0.09	0.08
	33 months	23	8	7	7	1.51	0.61	0.43	0.43	0.15	0.08	0.08	0.08
	t value	3.16*	0.65	0.77	0.0	4.06*	3.52*	6.82***	4.82**	3.33*	1.87	0.40	0.0
Pineapple	Pre cult	14	8	7	7	0.96	0.39	0.15	0.16	0.25	0.14	0.06	0.05
	33 months	19	7	8	11	0.54	0.15	0.22	0.26	0.15	0.09	0.08	0.09
	t value	1.01	0.89	0.68	1.25	0.72	1.35	1.03	1.46	1.01	0.86	1.42	2.09(P<0.1)
Pineapple – corn/peanut	Pre cult	18	9	8	7	1.47	0.46	0.17	0.18	0.42	0.18	0.07	0.05
	33 months	30	12	9	9	1.91	0.92	0.61	0.45	0.17	0.09	0.09	0.09
	t value	2.13(P<0.1)	0.69	0.93	1.85	0.76	1.84	5.05**	4.06**	1.79	1.73	0.60	1.88

* Significant at 5% level
** Significant at 1% level
*** Significant at 0.1% level

pineapple and corn/peanut A similar observation was also reported for Ultisols under rubber, which received normal dosage of phos phate rock[3] The final content of P was significantly different from the pre cultivated levels in the surface layers of soils with short-term crops

The distribution pattern for the combined content of Ca and Mg was apparent in the intercropped treatments Under corn and peanut rotation, significant differences were detected at all depths Under this treatment, the levels after thirty-three months were in the range of two- to three-fold the pre-cultivated content The highest levels of residual Ca and Mg were recorded from the highest input system, where significant differences were detected especially at the lower depths

The surface layers of all treatments generally indicated depletion of K However, the depletion was signifcant in the soils under naturals and in the treatment with corn/peanut Significant build-up in K occurred in the 45–60 cm layer of the plots solely cropped with pineapple hedgerows In general, the mobility of potassium was reflected in its low values, in contrast to the combined content of Ca and Mg

Overall Effect of Management on Soil Nutrient Dynamics

The observations indicate that the chemical properties of the soil were directly governed by the crop and its associated inputs Various cropping systems elsewhere had reported on significant increases in exchangeable bases especially when the plant residues were returned to the soil[11] Continued fertiliser use under long-term croppings also showed resultant favourable soil chemical properties when compared to pre-cultivated levels[12] Such changes include increase in pH Ca P and ECEC, and a marked reduction in Al saturation

In the present trial, marked increases in P, Ca and Mg were detected for actively-managed plots, *i e* plots with corn/peanut rotation This is clearly due to the amounts of fertiliser and lime used Even under fertiliser trials for rubber on an Ultisol, the use of phosphate rock raised pH and Ca levels[13] Under the non intercropped treatments, there was depletion of bases with time This concurs with the observation of Pushparajah and Bachik[14] where apart from the resulting acidifying effects under legumes and naturals, a sharp reduction of Ca was detected in the surface soils Evidence of downward K movement was shown in the plots under legumes and in the intercropped plots In a separate liming study on Rengam series[15], it was found that the K content of the soil solution was high indicating the relative ease the cation went into solution compared to Ca and Mg This reflects the high rate of leaching of K in the profile The build-up of K with depth is a consequent of this phenomenon and is also probably due to the low K buffering capacity of Rengam series[16] The soil K content generally decreases with more croppings and such a pattern is characteristic of potassium dynamics[17] In this study, the build-up of P, Ca and Mg represent the most distinct feature in the soil fertility dynamics

Yield of Intercrops and Performance of Rubber

The performance of the high input interrow systems with respect to yield was reported earlier[18] Four crops of peanut and three crops of corn were harvested The seventh crop (corn) yielded poorly due to non-uniform growth as a result of high acidity and the increasing effect of shade from the rubber rows As such this particular crop was not included in the foregoing discussion In the case of peanut (*Table 4*), the marked yield decline for the second and third crops was attributed to the effect of drought The yield increased dramatically when moisture was readily available The yield was expressed on the basis of the areas of the total interrow system For the treatment under corn/peanut, the yield of the last peanut crop was 76% of the first crop When combined with pineapple, the final yield was 54% of the first crop The planting density of peanut in the latter treatment was reduced since pineapple was introduced as replacement for papaya from the third crop onwards The yield of the first crop,

TABLE 4. MEAN FRESH POD YIELD OF PEANUT AND FRESH COB YIELD OF CORN

Interrow treatment	Yield (kg/ha)					
	Peanut sequence				Corn sequence	
	1	2	3	4	1	2
Corn/peanut	3 133	2 095	1 666	2 393	5 453	3 307
Pineapple – corn/peanut	3 304	1 198	1 138	1 777	5 267	2 389
LSD (0.05)	ns	795	ns	174	ns	ns

ns = not significant

then under papaya, was comparable to that obtained in the other system.

For corn, the two crops indicated a reduction in yield (*Table 4*). The yield obtained from the second crop was 61% of the first crop for the treatment under corn/peanut. A higher reduction was recorded in the highest input plots and was partly due to the loss of planting density. Inconsistent yield trends in relation to aluminium saturation was observed. For both corn and peanut, it can be inferred that the effect of lack of available moisture overrides the effect of the range of aluminium saturation encountered. This was apparent in the highest input plot where despite its lower aluminium saturation, the yield recorded was significantly lower than the other interrow system when considering the second crop of peanut.

The girth of *Hevea* (RRIM 712) was measured to gauge the performance of the main crop in relation to the interrow treatments. The girth increments at 150 cm height after twenty-seven months of planting are shown in *Table 5*. The girth of rubber under intercropping exceeded those of trees with interrows of naturals and legumes. The girth of trees under legumes were less than those of trees with a cover of grasses and weeds, during the initial stages but at forty-two months, the trees with legumes performed better. This observation is probably due to the competitive nature of legumes for moisture and nutrients during the early stage of their growth.

However, towards the later stages and under increasing canopy closure, the legumes started to decompose and release high amounts of nutrients. The total N content of the soils under legumes was marginally higher than those of the other interrow systems at this stage of growth. Generally, the nutrient status of the trees are considered to be above optimal with no visual deficiency symptoms. The girth of rubber under the intercropped treatments

TABLE 5. MEAN GIRTH OF RRIM 712

Interrow treatment	Mean girth (cm) at 27 to 42 months after planting					
	27 months	30 months	33 months	36 months	39 months	42 months
Naturals	20.7a	23.6a	26.6a	28.8a	32.1ab	33.0a
Legumes	19.9a	23.0a	26.2a	28.6a	31.3a	33.4a
Corn/peanut	22.6b	25.6b	28.9b	31.1b	33.3bc	34.6ab
Pineapple	22.7b	25.8b	29.4b	31.4b	34.0c	35.9b
Pineapple – corn/peanut	23.2b	26.4b	29.9b	32.3b	34.9c	36.3b
LSD (0.05)	1.4	1.7	1.3	1.4	1.7	1.8

Figures followed by the same alphabet are not significantly different.

indicate the collective effect of dolomitic lime and fertiliser inputs. Previous experience on liming trials also indicated this phenomenon[19]. The study so far indicates that intercropping enhances growth of *Hevea* and it can be envisaged that earlier returns from *Hevea* in these plots are achievable.

CONCLUSION

The use of fertilisers and the corrective input of lime influence soil fertility dynamics of the cropped *Hevea* interrows. Monitoring the chemical changes over thirty-three months revealed the following pattern:

- Decline in pH under all interrow systems, with the soils under the cropping combination of pineapple and corn/peanut showing a marked decrease by one unit from the maximum attained.
- Significant build-up of phosphorus, calcium and magnesium in the intercropped soils, with the maximum residual levels attained in the highest input system.
- Depletion of potassium in the surface soils of all interrow systems and build-up at the lower depths of intercropped soils.
- High effective cation exchange capacity and low aluminium saturation were detected over several croppings.
- The occurrence of phosphorus and nitrogen peaks is indicative of the moisture regime encountered.
- Intercropping has a beneficial effect on growth of *Hevea* due to the effect of added fertiliser and lime.

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