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EFFECTS OF NUTRITION AND HORMONES ON GROWTH AND APICAL DOMINANCE IN TEA (*CAMELLIA SINENSIS* (L.) O. KUNTZE)

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The effects of three levels of a widely used tea nursery fertilizer mixture containing N, P, K, Mg and SO_4 and hormones on growth and apical dominance were studied using free-growing plants of two vigorous TRI clones.

At the highest level of fertilizer (F2) the plants showed earlier bud-break and an increase in the number and duration of active phases, with a reduction of the dormant phases. These resulted in more growth and dry matter accumulation and in more lateral shoot growth than was obtained with lower levels of fertilizer (F0 and F1). Leaf production on both main and side shoots was increased at the higher levels of nutrition. The results showed that vigorous clones may benefit from higher levels of fertilizer application than the presently recommended rates.

Gibberellic acid (200 ppm) alone or with benzyl adenine (25 ppm) tended to cause earlier bud-break at F0 and F1 but not at F2. The percentage bud-break obtained at F2 was, however, similar to that obtained at F0 and F1 with the above hormones. GA_3 or GA_3 + BA also increased the height of the plant, the response persisting for at least a month starting a fortnight from the first application. Neither BA (25 ppm) applied alone nor IAA (200 ppm) stimulated bud-break, but IAA increased the height of the plants at the higher levels of fertilizer used. There was an interaction between fertilizer and hormones during the period when the hormones were effective in increasing height.

A relationship was found between the growth of the shoots, natural and induced, and that of the roots. The active plant had about twice the amount of feeder roots as the dormant plant.

Under Ceylon conditions the tea plant exhibits periodicity of growth and of dormancy (Bond 1942). In tea plants growing unchecked ("free-growing") the pattern of growth and branching suggested that apical dominance is greatest when the terminal bud of the main shoot is growing vigorously and least when the terminal bud commences growth following dormancy. This results in the control and release respectively of terminal and axillary bud growth of the side shoots, thus regulating the form of the plant (Kulasegaram 1969*a*).

The succession of the active and dormant phases seems to proceed to a large extent independently of nutrition and climate. However, the duration of these phases may be influenced by both these factors. Deficiencies of certain elements, particularly nitrogen, have been shown by de Haan (1941) to prolong the period of dormancy. Other workers (Bond 1945, Wight and Barua 1955) have implicated an insufficient nutrient supply to the bud as the cause of dormancy.

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Kulasegaram (1969*a*) suggested that certain classes of hormones may be involved in the regulation of shoot growth in tea, as exogenous applications of gibberellic acid and kinetin were effective in stimulating the growth of dormant buds. Further studies (Kulasegaram 1969*b*) showed that the roots of actively growing tea plants supplied a stimulus which caused early growth of grafted dormant shoots but that the roots of dormant plants did not produce such a stimulus.

There is evidence to show that the growth of the feeder roots in tea exhibits periodicity similar to the top parts of the tea plant (Wight and Barua 1955; Barua and Dutta 1961), which suggests a relationship between root and shoot growth. The periodicity of feeder root growth may be reflected in the "root-stimulus" (Kulasegaram 1969*b*).

The "root-stimulus" may be expected to include water and nutrients, both organic as well as inorganic, and root-synthesized growth factors (Selvendran 1970). Gibberellin activity has been detected in extracts of tea shoots (Kulasegaram 1969*a*) and in the xylem sap of tea plants (Selvendran 1970), but no assay has been done in respect of other growth factors, such as the kinins, which may also be present. Thus the root system may, by means of its periodicity of growth, exercise control over the supplies of water, nutrients and growth factors to the shoot and hence regulate shoot growth. Similarly root growth may also depend on metabolites and additional factors originating in the shoot, suggesting a close interdependence of root and shoot growth. Information on the interrelationship between feeder root growth and shoot growth in tea is lacking.

The object of the present investigation was to study the interaction between plane of nutrition and a supply of exogenous hormones in relation to growth and apical dominance and to obtain information on the relationship between root and shoot growth.

MATERIALS AND METHODS

Tea plants were raised under standard nursery conditions in soil in polythene sleeves 18 cm long and 9 cm in diameter. The soil used for striking cuttings was subsoil on which Guatemala grass (*Tripsacum laxum* Nash) had been grown for about 1½ years. It was a loamy soil of pH 4.85. Its nutrient status was: organic matter 4.82%, nitrogen 0.21%, phosphorus 7.20 ppm, and exchangeable cations (meq.%) potassium 0.17, calcium 0.76, magnesium 0.36. The control of pests and diseases was carried out as a routine measure. Fertilizer-T65 (Tolhurst and Visser, 1961) applications were begun when the plants were 12 weeks old and were applied uniformly until the differential fertilizer treatments were started 20 weeks later. The components by weight of the fertilizer mixutre were:

15 parts of sulphate of ammonia (20.6% N),
20 parts of ammonium phosphate (20.0% N; 35.0% P_2O_5),
15 parts of potassium sulphate (48.0% K_2O), and
15 parts of Epsom salts (16.0% MgO).

This mixture provides approximately 10.9% N, 10.8% P_2O_5, 11.1% K_2O and 4% MgO. The recommendation is to dissolve 1 oz (28.5 g) of the mixture in 1 gallon of water and to water about 100 plants with this quantity of the solution. This dose may be doubled when the plants show vigorous growth two months prior to planting them out in the field, which is done when they are 32-48 weeks old depending on the vigour of the clone. In the experiment reported here the recommended rate of 0.29 g of the mixture per plant was adhered to. The fertilizer application was repeated fortnightly. Following each fertilizer application the plants were washed with clean water to prevent scorching of leaves.

Single-stemmed uniform plants 22 weeks of age of two vigorous clones A and B† were selected for the experiment. The treatments consisted of three fertilizer levels and five hormone treatments. The differential fertilizer treatments, which commenced on 22nd November 1969, consisted of:

1. F0 = No further fertilizer.
2. F1 = 0.29 g/plant at fortnightly intervals.
3. F2 = 0.58 g/plant at fortnightly intervals.

The hormone treatments were started 7 weeks after the commencement of differential fertilizer applications and were given as foliar-sprays five times between the 10th and 24th January 1970 using a hand atomizer. The following concentrations of hormones found effective in preliminary experiments were used. All solutions included a wetting agent (Teepol at 0.05%):

1. Control—distilled water.
2. Indolyl-3-acetic acid (IAA)—200 ppm.
3. Benzyl adenine (BA)—25 ppm.
4. Gibberellic acid (GA_3)—200 ppm.
5. GA_3 + BA—sprayed separately with an interval of two hours between sprays.

The layout was of a randomized split-plot design with four replications. The three fertilizer levels were assigned to the main plots, which were split to accommodate the five hormone treatments. One hundred plants were used for each fertilizer treatment and twenty plants for each hormone treatment.

Weekly records were kept of the condition of the terminal buds of individual plants; fortnightly records were maintained of height and total number of leaves produced and retained on the main axis. A final assessment was made on 17th June 1970 when records were kept of the number and length of side shoots, total number of leaves retained on the plant and dry matter distribution. Analyses of variance on increase in mean height per plant were done on $\log_e(n+1)$, monthly mean differences in total leaf number per plant and mean number of side shoots per plant on $\sqrt{(n+1)}$ and leaves retained per plant on $\sqrt{n}$ transformed data.

RESULTS

Percentage of plants with active terminal buds

Effect of fertilizer

In both clones more plants remained in the active condition, and the peaks of activity were generally reached comparatively early, at the higher levels of fertilizer application (Fig. 1). It will be seen that while Clone A showed three peaks of active growth, Clone B had only two.

†Clone A = TRI 2026 and Clone B = 2025.

Effect of hormones

The effect of the foliar sprays of hormones, which commenced 7 weeks after differential fertilizer treatments had been started, is shown in Figure 2. In both clones at the F0 and F1 levels, GA_3 and GA_3+BA caused more plants to remain in the active condition about a month after the sprays were given. However, no clear differences in respect of these hormones were shown at the F2 level. Even at F0 and F1 the effectiveness of these hormones disappeared with time.

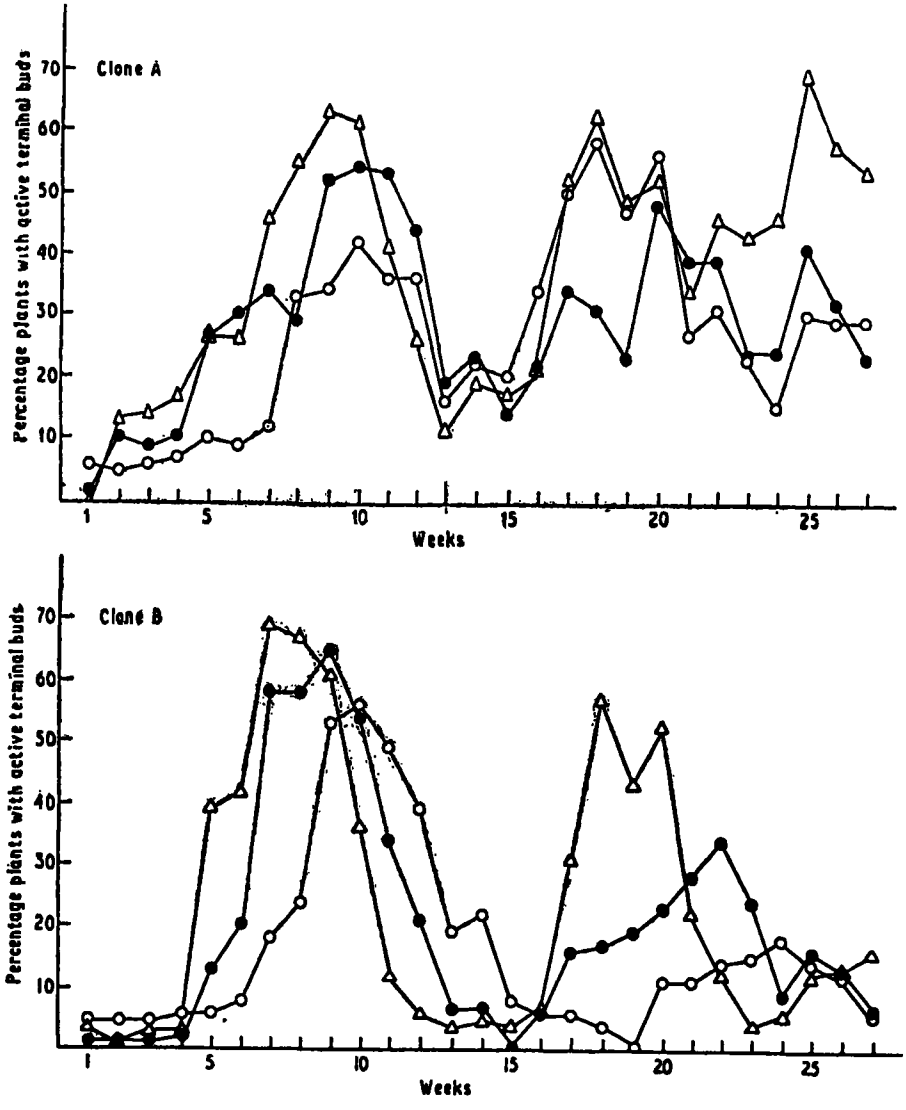

FIG. 1

Effect of level of fertilizer (T65) on percentage of plants with active terminal buds (means of 100 plants).
Top: Clone A, Bottom: Clone B.
○ = F0, ● = F1, △ = F2.

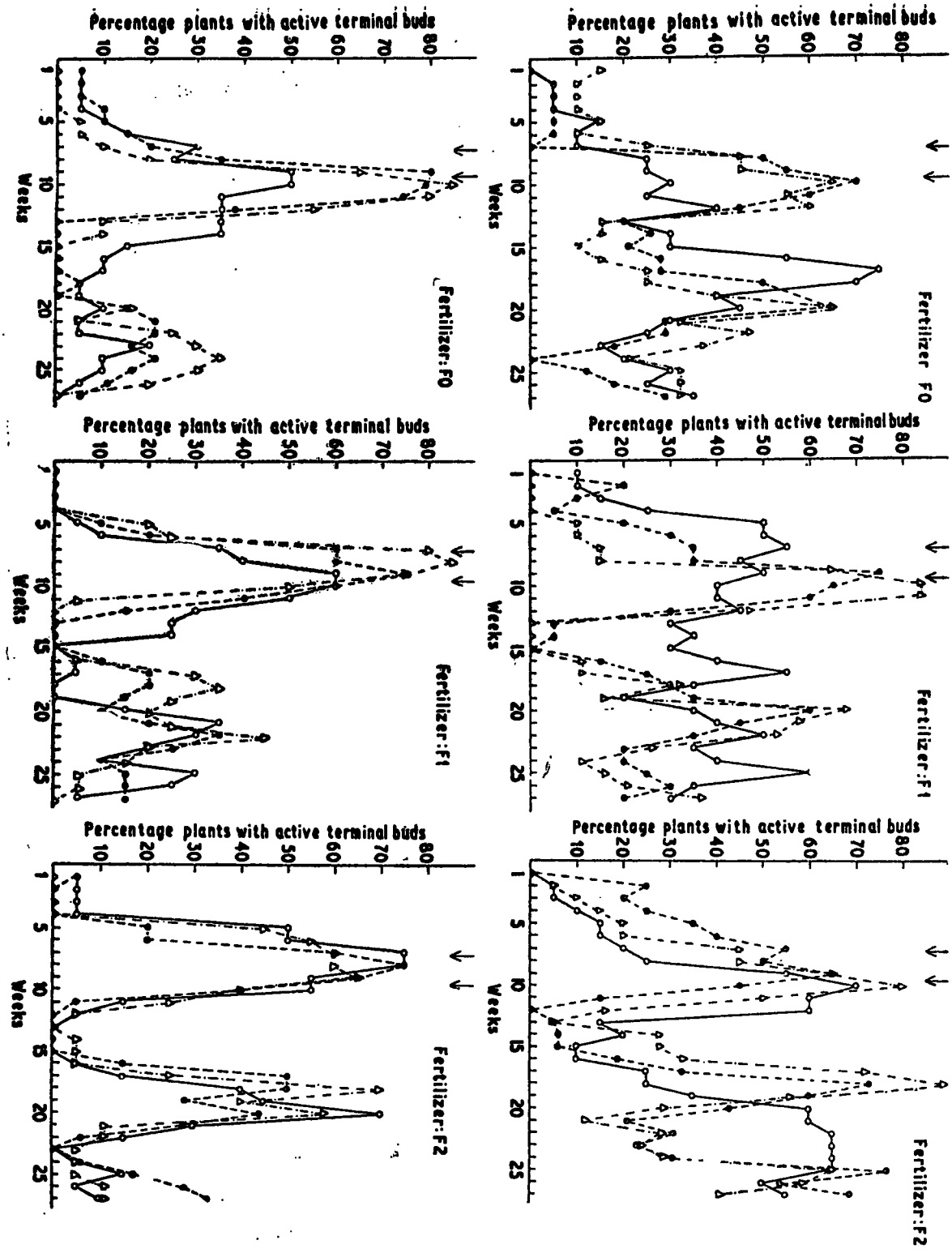

FIG. 2

Effect of foliar sprays of hormones on percentage of plants with active terminal buds (means of 20 plants). Top: Clone A. Bottom: Clone B.
Vertical arrows indicate period of hormone application. O = Control, ● = GA_3 Δ = GA_3+BA

Number and duration of active phases

Effect of fertilizer

In both clones the number, as well as the duration, of the active phases was increased by higher levels of fertilizer, thus increasing the percentage duration of growth (Table 1).

TABLE 1— *Effect of fertilizer and hormones on the mean number and duration of active phases per plant over 27 weeks in two clones*

	Active phases per plant					
	Clone A			Clone B		
	Number	Duration (weeks)	% Duration	Number	Duration (weeks)	% Duration
Fertilizer level						
F0	2.0	7.2±0.3	27	1.5	4.4±0.3	16
F1	2.4	7.8±0.2	29	1.9	5.6±0.2	21
F2	2.6	10.1±0.3	37	2.2	6.3±0.2	23
Hormones						
Control	2.2	8.9±0.2	33	1.7	5.5±0.2	20
IAA	2.4	8.9±0.2	33	1.9	5.3±0.2	20
BA	2.2	7.6±0.1	28	1.8	5.4±0.1	20
GA_3	2.4	8.2±0.2	31	1.9	5.5±0.1	20
GA_3+BA	2.5	8.2±0.1	30	2.0	5.6±0.1	21

Effect of hormones

In both clones the hormones generally increased the number of active phases per plant, but none of the hormones increased the duration of growth (Table 1). This was presumably due to the short duration of hormone treatment and to the assessment being made when the hormone sprays had lost their efficacy.

Increase in plant height

Effect of fertilizer

The progressive fortnightly increases in height of the two clones as affected by fertilizer level are presented graphically in Figure 3. In Clone A, which responded rather late to the differential fertilizer treatments, marked increases due to the higher fertilizer levels were seen after 8 weeks, while in Clone B differences were apparent after 4 weeks. The effects of higher levels of fertilizer on increases in height were highly significant ($P<0.001$) and continued to be maintained over the 22 weeks in both clones.

Effect of hormones

GA_3 and GA_3+BA increased plant height at all three levels of fertilizer used, but this effect was more marked at the higher levels. The effects of the hormones on increase in height averaged over the three fertilizer levels are shown in Figure 4. In general, significant responses due to GA_3 and $GA_3 \pm$BA were noted a fortnight following the first spray application and remained apparent for a further 4 weeks, but not thereafter.

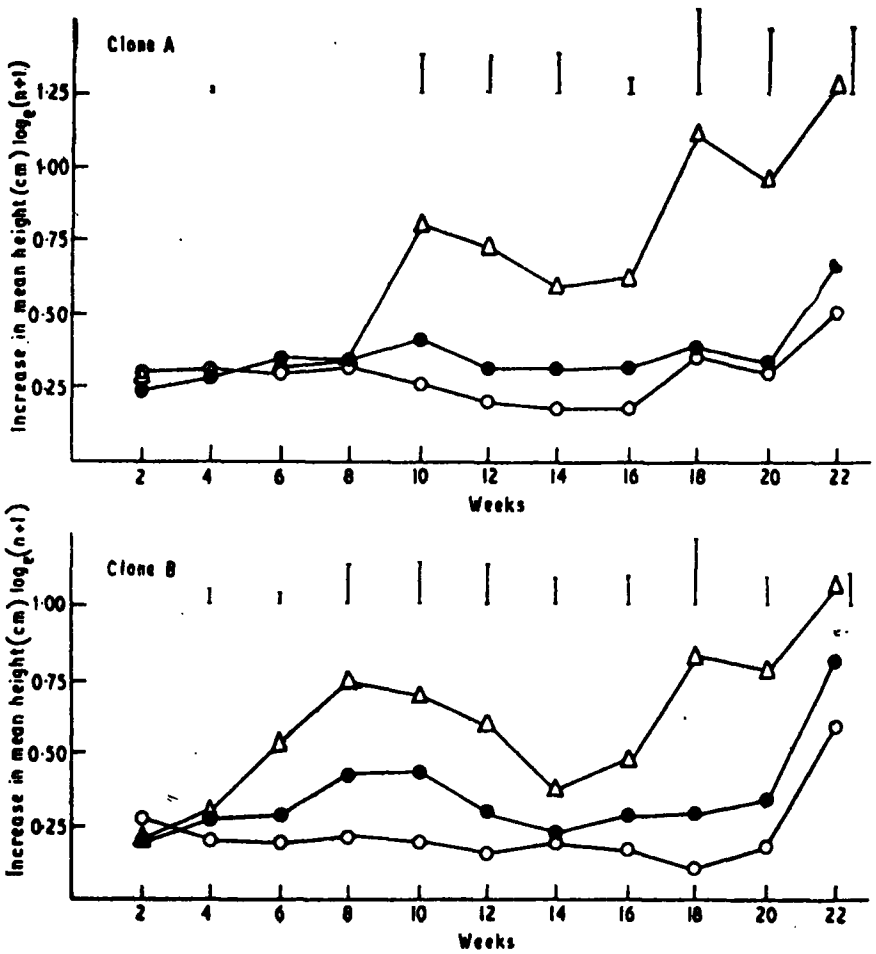

FIG 3

Effect of level of fertilizer on fortnightly increases in mean height (means of 100 plants).
Top: Clone A. Bottom: Clone B.
○ = F0, ● = F1, △ = F2.
Vertical lines = L.S.D. for $P = 0.05$.

Interaction between fertilizer and hormones

In both clones a significant interaction for height first became evident about 3 weeks after hormone applications were started. In Clone A a significant interaction for height was seen again 12 weeks later, while in Clone B a significant interaction continued to be maintained for a further 6 weeks. The nature of the interaction for Clones A and B are presented graphically in Figure 5.

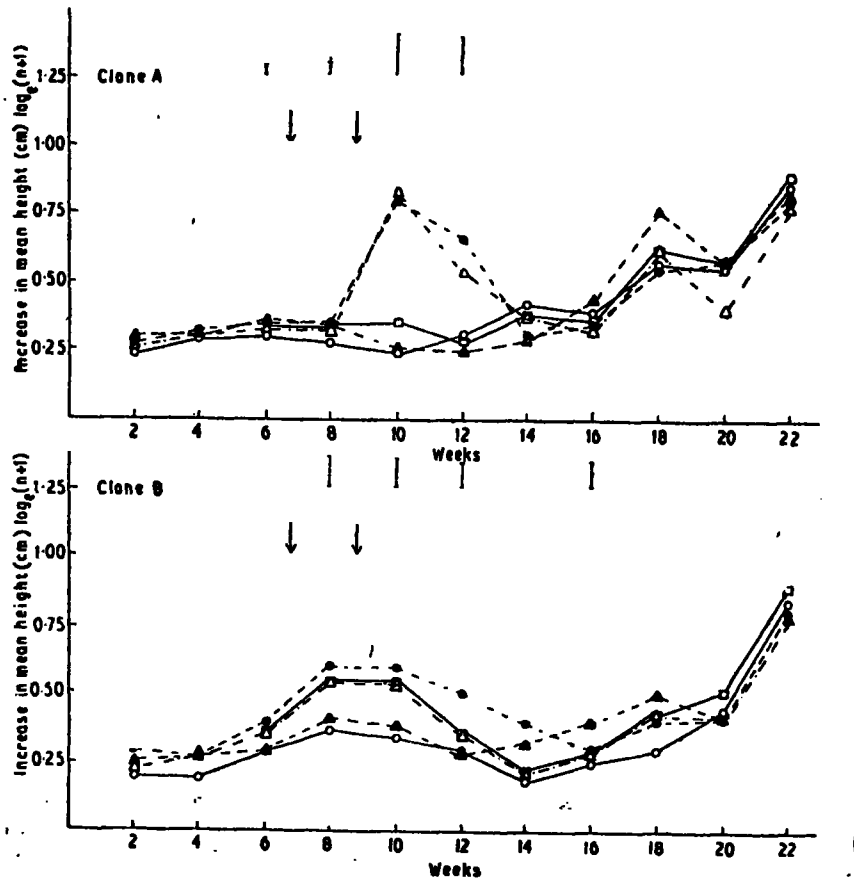

FIG 4

Effect of foliar sprays of hormones on fortnightly increases in mean height (means of 20 plants).
Top Clone A. Bottom: Clone B.
○ = Control, ● = GA_3, △ = GA_3+BA, ▲ = IAA, □ = BA.

Total number of leaves on the main axis

The total number of leaves produced on the main axis, as indicated by leaf scars and by leaves retained for a period of 20 weeks, increased significantly in both clones with increased levels of fertilizer (Table 2). In Clones A and B the effect of fertilizer level on leaf production lasted for 8 and 12 weeks respectively, commencing 8 weeks after differential fertilizer application.

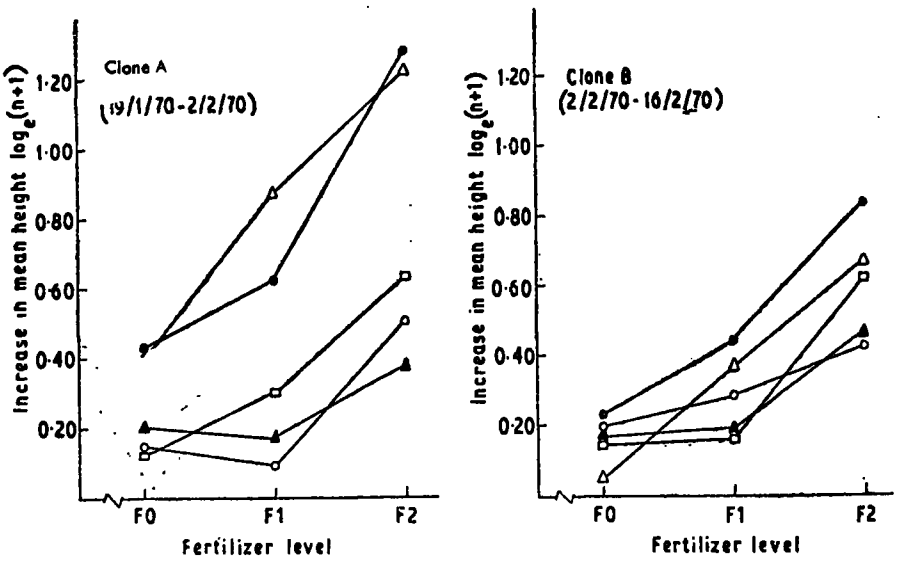

FIG. 5

Interaction between level of fertilizer and hormones on increase in mean height.
Left: Clone A. Right: Clone B.
○ = Control, ● = GA_3, △ = GA_3+BA, ▲ = IAA, □ = BA.

TABLE 2—*Effect of fertilizer (T65) on monthly mean differences in total leaf number (including leaf scars) per plant on the main stem (means of 100 plants)*†

Clone A

Fertilizer level	Months 1	2	3	4	5
F0	1.1 (0.2)	1.1 (0.2)	1.3 (0.7)	1.4 (1.0)	1.5 (1.3)
F1	1.1 (0.2)	1.2 (0.4)	1.5 (1.3)	1.3 (0.7)	1.3 (0.7)
F2	1.2 (0.4)	1.4 (1.0)	1.9 (2.6)	1.3 (0.7)	1.6 (1.6)
L.S.D. $P = 0.05$	N.S.	0.1	0.2	N.S.	N.S.

Clone B

Fertilizer level	Months 1	2	3	4	5
F0	1.2 (0.4)	1.3 (0.7)	2.0 (3.0)	1.5 (1.3)	1.4 (1.0)
F1	1.2 (0.4)	1.6 (1.6)	2.0 (3.0)	1.2 (0.4)	1.8 (2.2)
F2	1.1 (0.2)	1.9 (2.6)	2.6 (5.8)	1.2 (0.4)	1.6 (1.6)
L.S.D. $P = 0.05$	N.S.	0.3	0.2	0.2	N.S.

† Analysis on $\sqrt{(n+1)}$ transformed data. Figures in parentheses indicate back-transformed numbers.

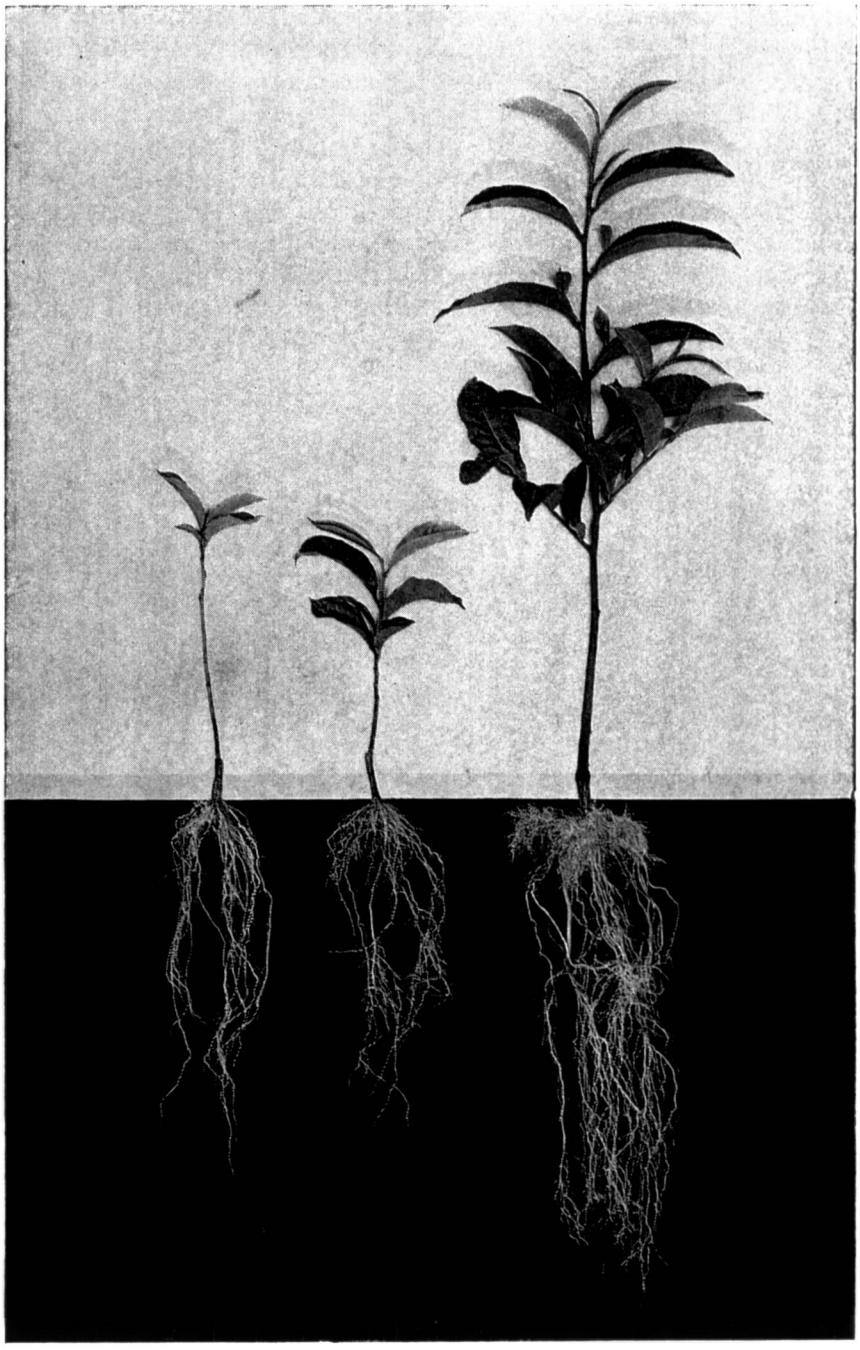

FIG. 6

Effect of fertilizer on growth and branching in Clone A (TRI 2026).
Left: no additional fertilizer (F0). Centre: 0.29 g T65 fertilizer/plant/fortnight (F1). Right: 0.58 g T65 fertilizer/plant/fortnight (F2).

Effect of fertilizer level on growth and dry matter production and distribution

The effect of fertilizer level on some of the growth attributes determined 27 weeks after differential fertilizer treatments had been started are presented in Table 3. Both clones responded markedly to the F2 level by producing more and longer side shoots, and the total number of leaves retained on the main and side shoots was also significantly greater than with F1 and F0. Although leaf areas were not determined, the data on leaf number and weight of leaves presented in the Table suggest that leaf areas in both clones were probably also increased at F2 compared with F1 and F0. It is also clear that the dry matter of leaves, stems and roots (plant) was greater at the higher level of fertilizer. In both clones at F2 a greater proportion of dry matter was found in the leaves than in the roots or in the stems. The effect of fertilizer level on growth and branching is shown in Figure 6, for Clone A.

TABLE 3—*Effect of fertilizer on growth and dry matter production (means of 100 plants)*†

	Clone A				Clone B			
	F0	F1	F2	L.S.D. $P = 0.05$	F0	F1	F2	L.S.D. $P = 0.05$
Mean No. of side shoots ‡ ..	1.3	1.3	2.0	0.3	1.2	1.4	1.9	0.2
(Back-transformed number) ..	(0.7)	(0.7)	(3.0)	—	(0.4)	(1.0)	(2.6)	—
Mean length of side shoots (cm) ..	1.3	2.1	20.4	7.4	0.6	4.5	9.1	5.0
Mean No. of leaves retained§ ..	2.9	2.6	4.6	0.4	3.4	2.8	3.9	0.3
(Back-transformed number) ..	(7.4)	(5.8)	(20.2)	—	(10.6)	(6.8)	(14.2)	—
Dry weight (g)								
Leaves ..	2.9	4.3	17.4	2.5	3.2	4.7	9.8	1.9
Stems	4.2	4.3	14.8	2.1	5.3	6.1	8.9	1.6
Roots	4.4	5.2	10.6	2.3	4.0	4.5	6.8	0.6
Plant	11.5	13.8	42.8	7.3	12.5	15.3	25.5	4.1

†Differential fertilizer applied from November 1969, assessed mid-June 1970

‡Analysis done on $\sqrt{(n+1)}$ transformed data.

§Analysis done on $\sqrt{n}$ transformed data.

Since hormones were only applied over a short period, their effects as seen from the results reported above were not prolonged. Furthermore, since information was sought on periodicity of terminal bud activity, the full complement of plants was retained throughout the experiment and hence information on the possible effects of hormones on some growth attributes could not be obtained at the appropriate time.

Relationship between shoot and root growth

Preliminary observations made on 44-week-old plants of a different clone, Clone C†, with either active or dormant terminal buds showed that when the terminal bud was active there was a correspondingly greater activity of the feeder root system (Fig. 7).

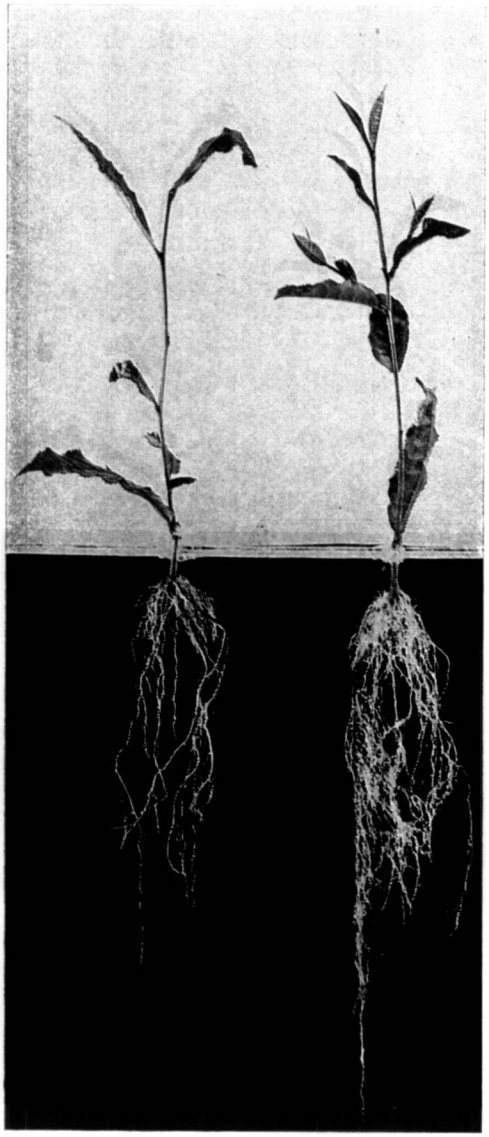

FIG. 7

Relationship between bud condition and root growth of 44-week-old plants of Clone C (TRI 2043).
Left : plant with dormant terminal bud. Right : plant with active terminal bud.

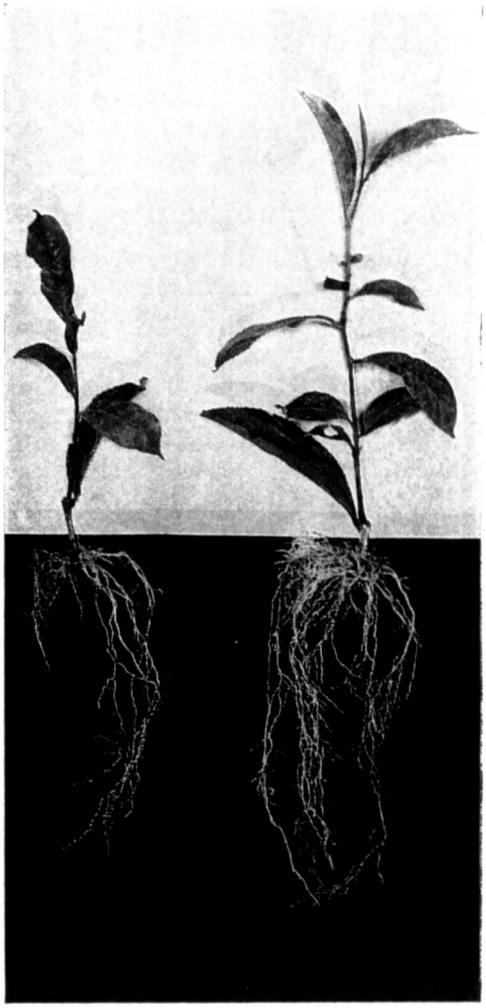

FIG. 8

Relationship between terminal bud condition and root growth of initially dormant 40-week-old plants of Clone D (TRI 2024).
Left : untreated control with dormant terminal bud. Right : plant treated on 21st August 1969 with a mixture of 0.75% ammonium phosphate, 0.75% zinc sulphate, 5 ppm kinetin and 25 ppm gibberellic acid. Length of shoot above tape indicates new growth made since treatment. Plants photographed on 27th September 1969.

Further experiments were conducted on 40-week-old plants of another clone, Clone D†, which had remained in the dormant condition for an appreciable length of time. These were forced into growth by spraying the plants with a solution containing 0.75% ammonium phosphate, 0.75% zinc sulphate, 5 ppm kinetin and 25 ppm gibberellic acid on 21st August 1969. Previous experience had shown that nitrogen, zinc, kinetin and gibberellic acid were all effective in inducing growth of dormant plants. Hence an attempt was made to include the above components at doses which had been found effective for this purpose. Plants which were sprayed with the above solution grew out of the dormant condition while untreated plants remained dormant. Figure 8 shows the additional growth of the shoot in the treated plant and the associated increased growth of the feeder roots.

Since preliminary observations on different clones indicated that there was a relationship between the size of the shoot and root systems, an experiment was carried out to quantify this relationship.

Plants of Clone C, raised in July 1968, were used when they were about 72 weeks old. Two sets of active and dormant plants were selected so that the position of the last dormant terminal bud of the active plants, as indicated by the position of the scale-leaf node, was comparable in height to that of the dormant plants. An analysis was done to see if the additional new growth of shoots above the last dormant bud in the active plant could be related to additional root growth. For this purpose roots were separated into "extension roots" and "feeder roots" (Barua and Dutta 1961).

There were thirty plants in each set with fifteen active and fifteen dormant plants. The roots of the plants were carefully washed in water to remove soil, and total fresh weights were determined after removing surface moisture. The white feeder roots were then clipped off and floated in water, and their number and total length determined.

The results of the relationship between shoot and root growth determined in Clone C are presented in Table 4. It will be noted that for the two sets of comparable active and dormant plants the root system of the former showed markedly more growth than that of the latter.

TABLE 4 — *Relationship between root and shoot growth in Clone C (means of 15 plants)*

	Set 1		Set 2	
	Dormant	Active	Dormant	Active
Height to point of last dormant bud (cm)	17.0±0.5	16.0±0.9	25.0±0.8	29.0±1.4
New growth (cm)	—	6.0±0.1	—	4.0±0.8
Fresh weight of old roots (g)	2.8±0.2	4.2±0.3	4.3±0.3	8.7±1.1
Fresh weight of active feeder roots (g)	0.06±0.01	0.1±0.02	0.03±0.006	0.1±0.02
Length of active feeder roots (cm)	31.0±6.5	62.0±8.2	—	—
No. of active feeder roots ..	20.8±4.1	44.5±6.6	—	—

The number, length and fresh weight of feeder roots, as well as the fresh weight of the old roots, in the active plants were about double those of the dormant plants. Attempts made to correlate new growth of shoot and root showed, however, that, although there was a relationship between the two, correlations between additional new growth of shoot (mm) and length of feeder roots (mm) ($r = 0.48$) and between additional new growth of shoot (mm) and number of feeder roots ($r = 0.49$), fell short of the 5% level of significance ($r = 0.51$). No relationship was found between new growth of the shoot and weight of the feeder roots.

†Clone D = TRI 2024.

DISCUSSION

The results of this investigation have clearly shown the importance of the level of nutrition in growth and branching in tea. The highest level of fertilizer applied (F2) caused more plants to grow earlier (Fig. 1), induced a greater number of active phases of longer duration and reduced the duration of the dormant phases compared with the lower levels F1 and F0 (Table 1). The responses to higher levels of fertilizer have contributed to enhanced growth in terms of increased height and dry matter accumulation (Table 3). In terms of dry matter distribution a relatively large proportion was found in the leaves and a relatively small proportion in the roots and stems at F2, whereas at F0 and F1 the differences in dry matter distribution in the leaves, stems and roots were less marked. The number of leaves produced on the main and side shoots per plant was significantly greater at F2 than at F0 and F1.

Although leaf areas were not determined in this study, the total number and weight of leaves produced per plant were such as to indicate that leaf areas were also correspondingly increased at the higher levels of fertilizer. Furthermore, it was also noted that branching was greatly enhanced at the F2 level as compared with F0 and F1 (Table 3). This may have been associated with the effect of a high level of nutrition in reducing the degree of apical dominance, thus releasing the axillary buds from inhibition by the active shoot apex.

The fertilizer used in this study contained N, P, K, Mg and SO_4, and the availability of all these must have been greater with F2 than with F0 and F1. Nutrient availability, particularly of N and to a lesser extent of K and P, can greatly influence the degree of apical dominance (Gregory and Veale 1957; McIntyre 1964, 1965). Bond (1942, 1945), working with tea, held the view that a restricted supply of nutrients to the buds resulted in dormancy. This conclusion was based on anatomical studies, in which he observed poor vascular connections to the growing apex in rapidly elongating shoots. De Haan (1941) has shown that a deficiency of N prolonged dormancy, and others have implicated insufficient nutrient supply to the bud as the cause of dormancy (Bond 1942, 1945; Wight and Barua 1955). It would thus appear that nutrient supply is a major factor in the mechanism of apical dominance. The active terminal bud of the main shoot might, because of its increased auxin content, be in an advantageous position to draw nutrients towards it, thus depriving the axillary buds of essential nutrients.

While most of the available evidence would seem to support the concept of competition for nutrients, the results of Phillips (1968) with dwarf beans are not entirely consistent with this explanation, because he showed that inhibited buds were not starved of nutrients. The effect of high levels of nutrition in reducing apical dominance is thought to be an indirect one mediated by the possible synthesis of cytokinins (Sachs and Thimann 1967). Insufficient nutrient supply to the bud may be due to poor vascular connections as well as to decreased uptake of available nutrients.

The root system of the tea plant has been shown to be subject to periodicity (Wight and Barua 1955; Barua and Dutta 1961). In the present study the active plants had more and longer feeder roots than comparable dormant plants (Fig. 8). Greater metabolic activity may be expected to take place in the actively growing feeder roots than over the entire length of the root system. It is thus possible that more nutrients are taken up by the active plant than by the comparable dormant plant. However, it was also shown that more plants will grow out of dormancy earlier at high levels of nutrition, thus suggesting that even dormant plants can make use of the available nutrients, though perhaps not so efficiently as active plants. This aspect merits investigation.

In terms of practical usefulness this study also served to test the adequacy of the presently recommended rates of the tea nursery fertilizer mixture. It was shown that vigorous clones may benefit from higher levels of fertilizer than the amounts used at present.

Foliar sprays of gibberellic acid, kinetin and adenine were earlier shown to be effective in inducing growth of dormant buds. In addition it was shown that there may be an interaction between the different hormones in their effects on bud-break and apical dominance (Kulasegaram 1969*a*). In the present study early bud-break was obtained with GA_3 and GA_3+BA at low fertilizer levels (F0 and F1) but not at a high fertilizer level (F2) when the bud-break obtained without the use of hormones was similar to that obtained at F0 and F1 with them. This suggested that the factor (s) necessary for bud-break are produced naturally at higher levels of nutrition. The hormones generally increased the number of active phases but their duration was unaffected. A better response might have been obtained if the assessments had been made earlier or the period of hormone treatments extended. GA_3 and GA_3+BA increased the height of the plant more at F2 than at F0 and F1. BA, at the concentration used, was not effective in inducing early bud-break when used alone. As in previous work, IAA did not stimulate bud-break but increased the height of the plant at the higher levels of fertilizer used.

In general, the response to hormones was measurable for over a month commencing a fortnight after the first application, the response disappearing thereafter with time. This was presumably due to the fact that the hormones were only applied over a relatively short period of 2 weeks. For a continuing response repeated applications at regular intervals may be necessary.

A significant interaction was found between the level of nutrition and hormones in an increase in plant height during the period when the hormones were effective (Fig. 5).

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