

## STUDIES IN THE YIELD OF TEA

### IV.—THE EFFECT OF CULTIVATION AND WEEDS ON CROP GROWTH.\*

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*Introduction.*—The culture of plantation crops lacks the settled tradition that lies behind farming practice in temperate lands. Tropical agriculture has borrowed ideas freely from temperate agriculture, in most instances imitating operations associated with annual crops. The most persistent of borrowed traditions are those which stress the need for thorough cultivation and the complete suppression of weeds. Their unquestioned acceptance in Ceylon has in the past overridden all other considerations, and differences in crop and circumstances have been given little consideration. The facts that annuals need a seasonal preparation of a seed-bed upon which small seed can germinate and in which young seedlings can grow, and that cultivation is in the first place intended to produce this seed-bed, are largely irrelevant to a perennial crop such as tea, which is generally raised in a nursery for a period varying from six months to two years before transplanting in the field. In addition, heavy rainfall has generally appeared to be a further reason for cultivation in order to 'aerate' the soil. The converse problem of soil-erosion control has only recently been adequately realized. Vigorous cultivation and clean weeding with a scraping instrument have in the past undoubtedly hastened the process of soil erosion on the generally steep slopes of Ceylon's tea area.

The study of cultivation problems has been slow both at home and abroad for lack of means of measuring and expressing in a quantitative form so qualitative a conception as 'tilth.' Only since doubts about the need of specially vigorous cultivation for annual crops were voiced at home have the still more cogent doubts about advocating it for perennial crops made any impression in Ceylon planting circles.

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\* Reprinted from *The Empire Journal of Experimental Agriculture* 1940, Vol. VIII, pp 269-79.

**Previous Work.**—The trials at Rothamsted and Cambridge have independently shown that some of the traditional notions in regard to cultivation would have to be revised. In a series of experiments on rotary cultivation, ploughing, sub-soiling, hoeing, and rolling, the outstanding results have been that 'thorough' cultivation affects germination and early growth by the production of a good seed-bed, but makes little or no contribution to final yield. On some occasions the contrary process of rolling has increased the crop. The only beneficial effect of cultivation during the period of crop growth is attributable to weed destruction. <sup>(1, 2, 3, 4)</sup>

The data on cotton and tea are more relevant to tropical conditions. Heath <sup>(5)</sup>, working on cotton, found no advantage in growth and development following specially deep cultivation. A pulverizing roller applied after the harrow gave a beneficial effect. For various reasons he doubts whether extra cultivation helps soil aeration. In the first place it produces no increase of nitrate in the soil. Furthermore, cotton can grow quite normally in containers hermetically sealed. Maize and barley have been grown in completely waterlogged tropical soils provided that the nutrient-supply was adjusted <sup>(6)</sup>.

Cooper <sup>(7)</sup> has tried various treatments on tea in Assam. The standard implement is a hoe which penetrates about 7 in. into the soil for deep hoeing, and for light work cuts a sod 9 × 12 × 3 in. and turns it over on to the bare space left by the last sod cut. The essential point is that the surface-soil is as completely severed from the lower layer as if it had been ploughed. To destroy weeds, one deep hoe at the beginning of the season is normally followed by six light hoes spread over six months. Cooper investigated various combinations in hoeing programmes along with hand-weeding and a scraping operation that destroyed weeds but did not appreciably stir the soil. According to Cooper's findings, cultivation conferred no benefits so long as weeds were controlled by scraping or hand-weeding. Deep hoeing damaged roots sufficiently to check growth early in the season. The consensus of opinion on a variety of crops is therefore against specially vigorous cultivation.

#### SCHEME OF INVESTIGATION

The chief source of information in the following investigation is a field experiment with tea that has completed a three-year pruning cycle (1936-9) in which the main factors studied were, — cultivation, weeding, and manuring. Set out in full, the comparisons, arranged in pairs, were:—

1. *Clean weeding v. selective weeding.*—Clean weeding involved the removal monthly of all weeds, and selective weeding the removal at the same time of all grasses and non-herbaceous weeds. Where necessary, the remaining weeds were slashed just above ground-level to prevent interference with tea plucking.

2. *Intensive cultivation v. normal cultivation.*—The former consisted of three cultivations per annum spaced at three-month intervals, except that the forking due in March was omitted owing to dry weather. Normal cultivation consisted of one forking only at the time the manures were applied. The type of cultivation was what is locally known as 'envelope' forking. A three-pronged fork is driven into the ground, levered backwards and forward, and slightly raised till a pocket forms behind it; into this, leaf-mould and green-manure are pushed, after which a fresh 'envelope' is made adjoining it across the width of the cultivation row. This leaves a ridge and hollow, and the series of ridges and hollows so formed run parallel to each other about 9 in. apart. The soil mass is not completely inverted.

3. *Double manuring v. single manuring.*—The single dose provided per acre: nitrogen 40 lb., phosphoric acid 30 lb., potash 20 lb. Applications were made annually. Every plot received one of each of the above main treatments so that all possible combinations were obtained within the compass of eight treatments.

4. *Adco compost v. 'no Adco.'*—Replications of the above treatments were laid down on six areas that had for the previous four years received 15 tons per acre per annum of Adco compost, and also on six corresponding areas not so treated.

The effects of these various treatments were studied in relation to three characteristics: (a) the resistance of the soil to the penetration of a probe; (b) the volume and depth-distribution of feeding roots; and, (c) the yield of tea. Details of the technique used are given in the following sections.

#### EFFECT OF CULTIVATION AND WEEDS ON SOIL RESISTANCE

The soil probe designed by Culpin<sup>(9)</sup> has given under our conditions a clear and definite picture of the deterioration of the macrostructure of the soil after cultivation. Sieving tests similar to the those carried out by Keen<sup>(9)</sup> were attempted, but proved unsatisfactory in a soil that carried a crop continuously and was permeated by roots of very variable dimensions.

(a) *Untrodden soil*.—For purposes of comparison, preliminary measurements were made on a fenced and untrodden area in the same field as that containing the experiment. This area was without crop, but was otherwise identical with the experimental area in all essentials. After 'envelope' forking, the ridges were lightly levelled in order to afford a reasonable datum line, and probe-measurements were made. Thereafter the land was divided up into six plots of which three, in randomized order, were covered with a 3-in. thatch of a tall grass (*Andropogon nardus*). In this condition they remained for 17 months. After 5 months, and again after 17 months, resistance-measurements were made with the probe. In doing this no trampling was done and the mulch was disturbed as little as possible. The results obtained give information on the effect of rain, wind, and sun on the permanence of the forking effect. Since there was marked similarity between the measurements at 5 and 17 months, the latter only are considered here in relation to those made at the beginning of the period.

Fig. 1a shows the soil resistance in lb. at successive  $\frac{1}{2}$ -in. depths up to 9 in. for the initial and final probe-surveys on mulched untrodden soil. The wearing-off of the cultivation effect has been negligible. The instrument has a constant due to friction and its own weight, amounting to some 8 lb. The extra force necessary to ensure penetration to 9 in. just after forking is 2 lb. and is actually more than that necessary 17 months later. The scale adopted is a very open one and shows differences that may well be ignored in any practical interpretation of the results. Fig. 1b gives similar traces for the unmulched plots; the resistance is throughout smaller than for mulched plots. The reason for this is obscure, but the point of interest is that the traces for the different times are identical, due allowance being made for the error of the determinations. This comparison of mulched and unmulched plots makes it clear that the heavy rain of two monsoons and the intermittent drying produce no crust on unprotected soil. This finding is in marked distinction to those of Hénin<sup>(10)</sup> on temperate soils at Versailles. Hénin describes the destruction of the macrostructure by rain, and the formation of a well-defined crust which the removal of the probe occasionally detached from the general soil mass. Evidently the crumb structure of this Ceylon soil is more water-stable than that of Hénin's soil. This divergence cannot be regarded definitely as of general significance in distinguishing temperate and tropical soils until confirmatory data are available, but it is noteworthy that the greater water-stability of tropical soils is recognized as a factor in minimizing soil erosion, and has been commented upon in this connexion by the writer<sup>(11)</sup> and by Jacks and Whyte<sup>(12)</sup>.

(b) *Trodden soil*.—The soil between the rows of tea (usually 4 ft. apart) is constantly trampled after cultivation. For purposes of plucking, weeding, and shade-tree control there is traffic under all conditions at approximately weekly intervals. Very frequently the soil contains so much moisture that in temperate agriculture no work on land in a comparable physical state would be contemplated. The effect of this treading on the soil macrostructure is marked.

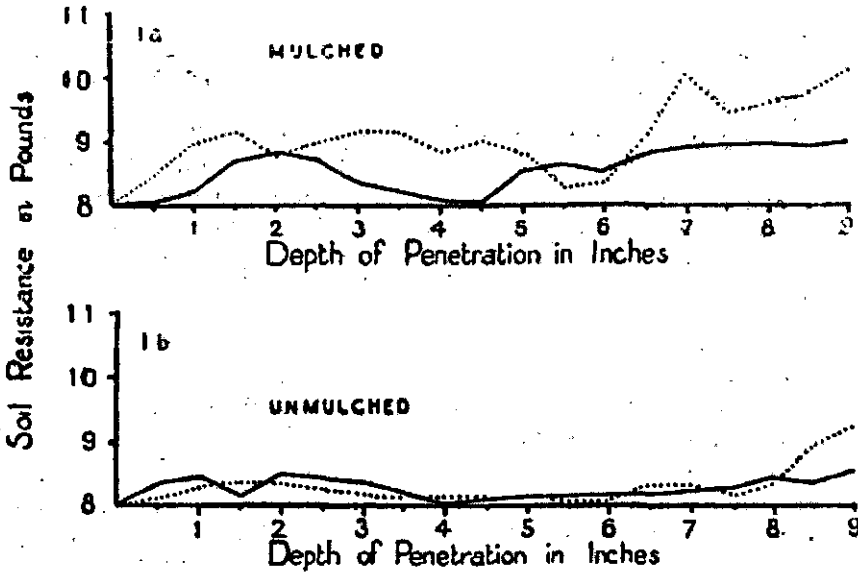


Fig. 1. Soil-resistance measurements. Dotted line: immediately after cultivation. Continuous line: seventeen months later.

Fig. 2a shows two soil-resistance curves taken  $2\frac{1}{2}$  years after the previously mentioned field experiment had been started, i.e., when the differing treatments had been given time to become effective. One curve represents the mean values for normal cultivation (N.C.) and the other for intensive cultivation (I.C.). Disregarding for the moment their difference in detail, both follow a definite pattern. They show a rise in resistance in the first  $1\frac{1}{2}$  to 2 in., followed by a decrease to a new minimum between 4 and 6 in., after which there is a sharp rise in the region of less-disturbed soil till finally an approximately constant value is reached beyond the depth of cultivation. Fig. 2c gives similar data from a small-holding which, as far as is known, has received no cultivation in the ordinary sense since the original planting. From time to time weed-growth has been scraped off without any soil-stirring. The same general curve-form is shown. The formation of a resistant crust due to treading is very evident and contrasts with its absence in Fig. 1.

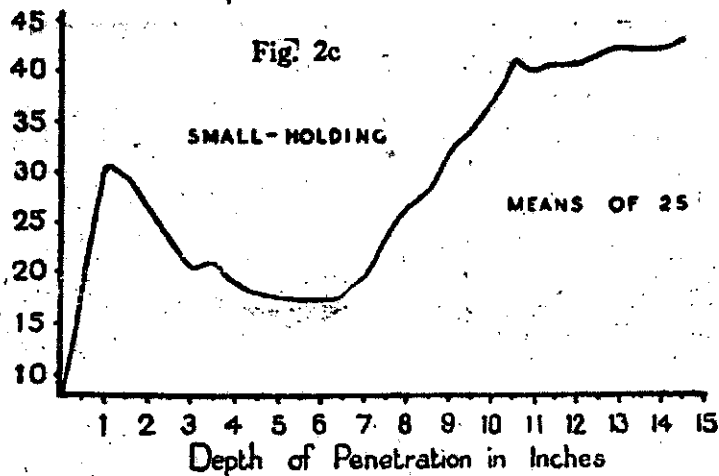
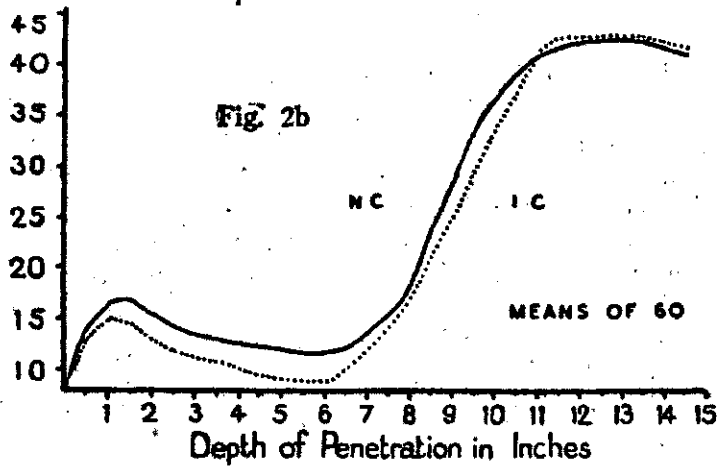
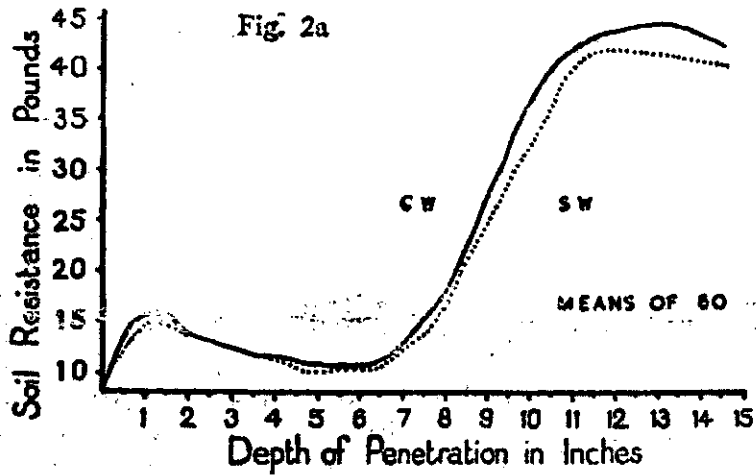


Fig. 2. Soil-resistance measurements: (a) Normal cultivation (N.C.); intensive cultivation (I.C.) (b) Clean weeded (C.W.); selectively weeded (S.W.) (c) Uncultivated small-holding

In greater detail Figs. 2a and 2b show the effect of intensive cultivation and weeding on the general shape of these curves. The curve for normal cultivation (N.C.) represents the position 9 months after a cultivation operation, whereas the intensive cultivation (I.C.) plots had been worked on only 3 months previously. Even with intensive cultivation, a treading crust rapidly forms under conditions heretofore described. The more frequent cultivation reduces resistance, though but slightly. But after 9 months' treading, the region beneath the surface-crust is still remarkably open and after 3 months is demonstrably in the same condition as at the time of forking. Fig. 2b shows that a weed-cover makes no difference to the formation of the trampled crust. This crust effect may be compared with that formed on English farms by sheep-treading, except that in tea soils it is completely dissipated by the type of cultivation subsequently employed.<sup>(15)</sup>

It will be shown later that the crust appears to have no effect on the development of the root-system; but it has an important relationship to soil erosion. Lowdermilk<sup>(14, 15)</sup> has shown that the formation of a silted and puddled surface-layer of soil determines the percolation-rate of rainfall for the entire soil profile, and thus regulates run-off. Gorrie<sup>(16)</sup> draws attention to the trampling of soil on heavily grazed grasslands in the same connexion. This type of percolation-control, undoubtedly occurs on tea soils. It is commonly observed that where a trodden path crosses a drain or silt-pit capable of collecting run-off, there is invariably a cone of deposited soil heaped up against the vertical drain-wall on the upper side.

#### EFFECT OF CULTIVATION AND WEEDS ON ROOT DISTRIBUTION

The main difficulty in root-investigations is to perfect an adequate technique. The system of selection of typical bushes from whose roots soil is washed away, so that roots can be photographed or plotted *in situ* with regard to a reference frame, has been used with success for a plantation crop by Nutman.<sup>(17)</sup> The usefulness of this method depends on the degree of certainty with which the small number of chosen bushes can be regarded as typical, and serves well to establish qualitative differences of root-structure either between related species or between markedly different habits. It is ill-fitted for studying the effects of cultivation treatments where less importance is attached to minute detail of root-disposition than to the general reaction to treatments within the range of their effectiveness. As an alternative capable of giving a quantitative picture, a method of random soil-sampling and root-separation has been

adopted. This has not been wholly satisfactory, though for each treatment 48 samples were examined. The technique adopted was as follows:—

Samples were taken midway between the rows of tea with a wrought-iron box sampling-tool measuring 8 × 8 × 3 in. This was driven into the soil with a wooden ram, and on two opposite sides the soil was cleared to the depth of the lower edge of the tool, *i.e.* 3 in. By using a curved-handled turf-lifter inserted underneath the tool, the block of soil in its container could be cleanly sliced from its position. This procedure was repeated for eight successive 3-in. depths without any great difficulty and without undue excavation for working-space. When trial samples were washed out it was found that the lowest layer contained on the average only about 4 per cent. of the weight of roots separated from the whole 24-in. soil prism. This depth was adopted in subsequent samples, since it was greater than the cultivation-depth and was well below the region in which the soil probe-resistance became stabilized. The roots were easily floated off from the soil by running a stream of water over the sample and stirring the soil meanwhile in a shallow, lipped container. The overflow was passed through a small sieve in which the clean roots were collected ready for drying and weighing. Only feeding-roots were recorded.

Since the sample size was quite arbitrary and only comparable values are required, the results for the various treatments are expressed on a percentage basis (Table 1).

TABLE I

Effect of Cultural Treatments on Total Root-weights  
to a depth of 24 in.

Treatment	Per cent. mean weight (means of 48 samples)
(a) { Normal cultivation ...	105
{ Intensive cultivation ...	95
(b) { Clean weeding ...	96
{ Selective weeding ...	104
(c) { Single manure ...	99
{ Double manure ...	101
(d) { With Adco ...	103
{ Without Adco ...	97

The differences between the individual constituents of the pairs are in no instance significant at the  $P=0.05$  level of probability, though the effect of intensive cultivation is nearly so. Possibly with a larger number of samples a negative result might have been avoided, but an increase in sample number would have created difficulties. Altogether 768 sub-samples were examined. Sampling was quicker work than washing, and a larger number of samples would have meant either a longer sampling or a longer storage period, neither of which was desirable.

In any case the results show that treatments of this type have a very narrow range of effectiveness in destroying mature, or in stimulating new, roots. In view of yield-differences to be reported in a later section, the figures for Adco are of particular interest. They give no support to the suggestion frequently made in Ceylon that bulk manure enhances root-growth apart from its effect on plant-nutrition.

The sampling of the roots by sections enabled the distribution of feeding-roots to be studied. In addition to the survey carried out on the cultivation-experiment, two further areas were included in the investigation. One was a similar area carrying older tea, and the other was a dissimilar area consisting of the aforementioned small-holding. The weight of roots in each sub-sample is expressed as a percentage of the total root-weight (Table II).

The first 12 in. of soil in the three localities contain about 70 per cent. of the roots. It was originally thought that the even distribution in the first 12 in. was due to cultivation, since the depth corresponds closely with the depth of soil-stirring as shown by probe-measurements. But when the small-holding samples were complete, the similarity in pattern maintained by the depth-distribution figures showed that conjecture to be ill-founded. It appears likely that the similarity is due more to uniformity in soil than to soil treatment. That there is a marked difference in total roots, as a result of cultural treatments, is shown by the last line of the table, which gives the total root-weights from the old and small-holding tea as a percentage of the young tea.

#### EFFECT OF CULTIVATION AND WEEDS ON CROP YIELDS

The most complete picture of the effect of cultural treatments on tea is given by the crop yields. The area used for the experiment was originally clean weeded and received uniform cultivation of the type here described as normal. Some time elapsed, therefore, before the effect of treatments became evident. Table III shows

the gains and losses due to weeds and cultivation in combination with other variable treatments. Displayed in this way, the interactions between treatments are easily demonstrated, but in point of fact none of them was significant. From inspection of the mean yields (to which criteria of significance are attached) the effect of treatment is seen to start in the second year and to be maintained through the third year. Treatment effects are significant over the three-year cycle considered as a whole. The extent of the weed effect is surprisingly small. Cultivation has had a definitely significant but small adverse effect. The non-existence of an interaction between weeds and manurial dose is of particular interest. Admittedly the extra dose was a heavy one for such young tea, and has sufficed for the requirements of both tea and weed-cover.

TABLE II

Distribution of Feeding-roots in successive 3-in. Layers  
(Percentages of Total Root-weight)

Layer (in)	Young tea (Experimental plots) cultivated	Old tea cultivated	Small-holding uncultivated
0-3	18	16	16.5
3-6	18	17	17
6-9	19.5	17.5	17.5
9-12	17.5	17.5	16
12-15	10.5	13	11
15-18	7	8.5	9
18-21	5.5	6	7
21-24	4	4.5	6
Total	100	100	100
Per cent in first 12 in.	73	68	67
Total root-weight as per cent. of young tea	100	155	50

TABLE III

## Effect of Cultivation and Weeds on Crop Yield

## A. Gain or Loss in Yield due to Weeds; lb. per acre per annum

Treatment	1st year	2nd year	3rd year	Cycle
Intensive cultivation ...	-5	-53	-51	-37
Normal cultivation ...	-13	-107	-43	-54
Single manure ...	-9	-77	-50	-46
Double manure ...	-9	-83	-43	-45
Mean ...	-9	-80**	-47**	-46**
Percentage ...	5.0	10.0	7.5	8.6

B. Gain or Loss in Yield due to Intensive Cultivation;  
lb. per acre per annum

Treatment	1st year	2nd year	3rd year	Cycle
Clean weeding ...	-4	-75	-33	-37
Selective weeding ...	+4	-21	-41	-20
Single manure ...	+6	-23	-18	-12
Double manure ...	-7	-73	-55	-45
Mean ...	3	-48*	-37*	-28*
Percentage ...	0	6.0	5.9	5.3
Mean annual yield per acre per lb. ...	180	798	627	535

Significant values  $P=0.05^*$ ;  $P=0.01^{**}$

### EFFECT OF BULK MANURE ON YIELDS

The effect of the pre-treatment of the sub-blocks with Adco manure was apparent throughout the whole experiment. Visual inspection of the plots showed that those areas receiving the bulk manure produced rows of tea that covered the ground more completely than their counterparts not so treated. The most striking difference was between the shade trees (*Erythrina lithosperma*) on the two areas: establishment and growth were good where Adco was applied, but were a failure elsewhere.

The total amount of plant-nutrient applied as bulk manure was considerable and the yields have benefited accordingly. After pruning, and before normal plucking started, the young developing shoots are allowed to grow for some 4 months and then tipped, i.e., broken back to 4 in. from the pruning-cut. The dry weights of this new growth were found to be 217 lb. per acre for Adco plots and 111 lb. per acre without Adco. Table IV gives the effect of Adco over the whole cycle and the effect of Adco on the yield-increases due to the application of artificial manure.

The tipping operation, being a levelling one, robbed the yield-difference in leaf for the rest of the first year of its significance, but thereafter a highly significant effect was produced. There was no significant interaction between Adco and the different levels of artificial manuring.

TABLE IV

Effect of Adco and Artificial Manure. Yield-increase in lb. per acre due to Adco

	1st year	2nd year	3rd year	Cycle
Single manure with Adco ...	31	151	146	110
Double manure with Adco...	35	169	169	124
Mean ...	33	160**	158**	117**
Percentage ...	8.3	20.0	25.2	21.9
Mean yield per acre ...	180	798	627	535

## DISCUSSION

The results of the investigations here reported have a definite bearing on agricultural practice on tea estates in Ceylon. They tend to confirm the view that moderation in all cultural operations gives the best results. No extra crop is to be expected from frequent cultivation, a result consonant with Cooper's findings (*loc. cit.*). As far as can be told, the intensive stirring of the soil makes no difference to the distribution of the root-system; and is no help at all, but probably a hindrance, to the production of a large volume of feeding-rootlets. The slight pan that is formed by the constant treading does not impair the distribution of roots in that region, and the main reason for forking as judged from these experiments is to break up that pan in the interests of soil erosion and run-off control, rather than to obtain living-room for the roots. Annual forking is ample, and the spreading of that operation over two six-month periods in alternate rows (a method very common in Ceylon in order to provide an occasion for the working-in of artificial or green manures as the latter mature) offers adequate soil disturbances to ensure good growth and yield.

The practice of clean weeding is shown on a short-time basis to give the best yield results, but the yield premium it gives is surprisingly small. If grasses are removed and other weeds controlled, a more or less complete carpet of soft weeds interferes but little with yield-potentialities, even in young tea where the lack of density of the major crop makes their growth quick. The practice of choosing, as a result of an actual trial, some three or four weeds which will give adequate protection against soil erosion, and of checking any slight yield-decline by extra manuring, appears to have distinct possibilities in conserving soil. On the basis of these experiments, the fear that the weeds, not the tea, would get the manure appears ill founded.

It would be premature to suggest that, since tea is a forest species, it should be allowed to grow under unrestricted or nearly unrestricted forest conditions. When a plant is taken as a crop plant, interference with its normal habits of growth must follow, and with tea the interference is severe. Without pruning, the crop of young leaf suitable for manufacture would be insignificant, and, since rapid growth of young shoots is desired, free play to the stabilizing influence of natural ecological competition seems impossible. But there is room for a movement away from extreme positions in the interests of soil conservation.

## SUMMARY

1. The effect of intensive cultivation, and of leaving a selected weed-cover in a tea experiment is described with respect to (a) soil resistance, (b) volume and distribution of roots, (c) yield.

2. Tea soils under cultivation programmes of very varying intensities show a characteristic pattern in their resistance to the Culpin soil-probe at depths up to 24 in. A surface-crust forms, not as a result of rain or other weather conditions, but as a result of continual treading. Beneath this crust the soil remains porous for a considerable time after cultivation. The surface-crust is an important predisposing cause of erosion.

3. Root-development also shows a similarity in distribution irrespective of cultivation, but root-volumes are markedly different under different cultural conditions. Intensive cultivation probably, but not certainly, decreases root-growth. A technique of root-sampling is described.

4. Both weeds and intensive cultivation reduce yield, the former by 8.6 per cent. and the latter by 5.3 per cent. over a three-year period.

5. The effect of bulk manure on yield and root-growth can be explained only on the assumption that the mechanism is entirely nutritive, and that bulk manures do not stimulate root-growth in any other special way.

6. The bearing of these results on plantation practice is discussed.

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