PRODUCTIVITY GRADIENTS ON SLOPING TEA LAND IN CEYLON

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Introduction

Laycock (1955) investigated the effect of plot shape in reducing the errors of tea experiments. He found that in Nyasaland and Ceylon (Eden, 1931) the error is reduced when the plots within the blocks are arranged to run with the slope rather than across the slope. Apparently, positional variation between plots in a block was less for narrow plots running up and down the physical slope. It might be implied from these results that soil heterogeneity and the corresponding variability of crop vigour were greater along than across the slope.

Topography, as one of the main factors of soil formation, affects the type, direction and rate of reactions that may occur during the transformation of a parent material to a soil material and a soil profile (Soil Survey Manual, 1951). It also affects the displacement of soil.

Mass movement of soil is not only a factor in the denudation of land under natural conditions, but it also plays an important part in the acceleration of soil removal as the result of cultivation. It is, therefore, intimately associated with soil erosion.

Downslope movement of superficial soil, often referred to as soil creep, generally proceeds over the entire area of a slope between streams and gullies and is one of the processes that keep soil profiles on slopes (alternatively, the steep upper part of a slope) thinner than on level land (alternatively, the lower part of a slope).

It is for these reasons that soil heterogeneity along a slope might be explained, displacement of topsoil down a slope affecting potential soil productivity in such a way that the lower parts of a slope would be or become more productive than the upper part.

In this study soil heterogeneity on sloping tea land is assessed with the help of observations on crop vigour and soil profile characteristics.

Experiments

Observations were made in three experiments.

1. *Clonal trial, St Coombs Estate*

Tipping weight of the guard rows (clone TRI 26) of 16 sub-blocks of a clonal trial at St Coombs (Kehl, 1963) were recorded in September and December 1962. Eight of these sub-blocks were inter-planted with Dadap shade trees. The experimental area was divided by a road, 5 and 11 of the sub-blocks being situated at the upper and lower side of the road respectively. The trial area was planted in 1961, the distance along the slope from the uppermost to the lowermost block being 200 yards approximately.

2. *Confounded NPK-trial, St Coombs Estate*

The design of and results obtained in this trial were given elsewhere (Hasselo, 1963 and 1964). Block 5 of the six blocks of this trial was situated on a steep but uniform slope. Tipping weight of the guard rows (clone TRI 26) surrounding the ten plots of this block was recorded in June, October and December 1963, *i.e.* 11, 15 and 17 months after planting, and related to the position of the plants on the slope.

3. *Depletion of root-starch trial, Glenlyon Estate*

The design of and the results obtained in this trial were discussed elsewhere (Hasselo, 1962 and 1963). Root-starch contents of plants in 16 plots were compared with position of these plots on the slope and with soil profile characteristics, as assessed by means of soil borings.

Results

1. *Clonal trial (St Coombs)*

The 16 sub-blocks of this trial were arranged in eight classes according to their elevation, class 1 being at the lower end of the slope and class 8 at the crest (figure 1).

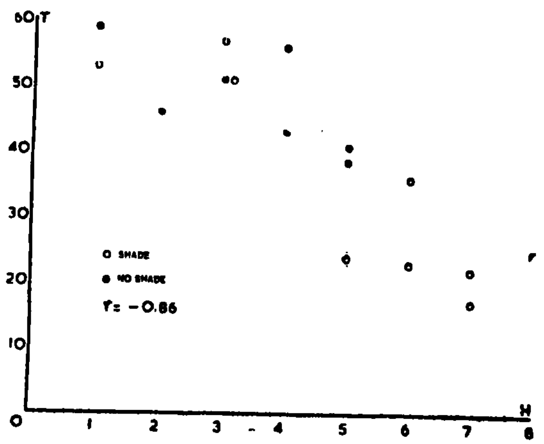

Figure 1.—The relation between tipping weight (T=total weight in kg of tippings in September and December 1962 of, on average, 135 guard row plants (clone TRI 26) per sub-block) and position on slope (H); class 1 lowest, class 8 highest position on slope.

It will be seen from Figure 1 that productivity of the land was closely (r= −0.86) and significantly (P=0.001) related to its position on the slope. In fact, almost three quarters (r^2=0.74) of the total variation in plant vigour could be attributed to position on the slope. As the distance between the highest and lowest block was approximately 200 yards and the tipping weights amounted to about 15 kg and 60 kg respectively, there was an increase in productivity of 1½% per yard down the slope in this trial.

2. *NPK trial (St Coombs)*

It will be seen from Figure 2 that tipping weights of the plants situated lower down the slope increased (r=0.63, significant at P=0.001) from, on average, 269 g/plant at the top to 352 g at the lower end of the block, or by about 31%. Forty per cent (r^2=0.40) of this increase was due to the plant's position on the slope. As the distance between the lower and upper row of the block was 44 feet, the productivity of the land increased by some 2% per yard down the slope.

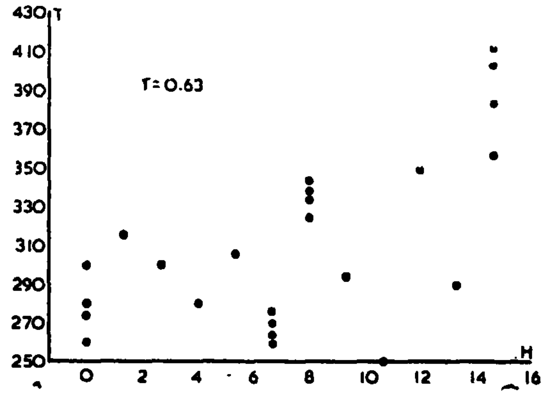

Figure 2.—The relation between total tipping weight (T in g/plant; mean of 14 guard row plants of clone TRI 26) of tippings in June, October and December 1963 and position on slope (H in yards down the slope).

3. *Root-starch trial (Glenlyon)*

Root-starch contents obtained in the 16 plots of this trial and soil profile scorings are shown in table 1.

Table 1.—*Root-starch contents (R in %; mean of 4 sample assessments made in March, May, July and September 1962 respectively) of seedling tea and number of good marks scored for soil profile characteristics: P, C, O and G.*

P=position on slope; the higher the elevation of a plot on the slope the fewer good marks are given. The highest plot received no good marks, the lowest plot 3.

C=presence (no good marks) or absence (one good mark) of predominantly clayey subsoil within 4 feet from the surface.

O=thickness of organic top layer: the thinnest and thickest layers obtaining 1 and 3 good marks respectively.

G=absence (no good marks) or presence (one good mark) of gravelly layer in subsoil.

R†=8.9 (P=0) (C=0; 0=1; G=1)	13.6 (1) (1; 3; 0)	10.1 (1) (0; 2; 0)	11.8 (2) (1; 1; 0)
11.4 (1) (0; 3; 1)	11.6 (2) (0; 1; 0)	11.3 (1) (1; 2; 0)	9.4 (1) (1; 2; 0)
12.3 (2) (1; 2; 1)	13.0 (2) (0; 2; 1)	14.2 (2) (1; 3; 0)	11.0 (2) (0; 2; 0)
11.0 (3) (0; 2; 1)	15.7 (3) (1; 3; 1)	12.9 (3) (1; 1; 1)	14.9 (3) (1; 2; 1)

†root-starch figures corrected for significant effect of pruning on root-starch (see Hasselo, 1962 & 1963) Adjustments made on basis of row and column totals.

TABLE 2.—*(Partial) correlation coefficients (for explanation see Table 1)*

Correlation	P	C	O	G	T= C+O+G	Partial correlation	
root-starch (R)	0.656††	0.514†	0.103	0.236	0.682††	$r_{RP.T}$	0.562†
position on slope (P)	—	0.243	0.000	0.495	0.414	$r_{RT.P}$	0.597†

†sign. at P=0.05
††sign. at P=0.01

It will be seen from tables 1 and 2 that even the plant's root-starch contents, which are known to fluctuate considerably owing to seasonal variations and sampling errors, are significantly related (r=0.656) to position on the slope. Using root-starch content as an index of soil productivity, the plots situated lower down the slope had the more productive soils. An equally good relationship was obtained (r=0.682) between root-starch and the sum total of the scorings made in respect of organic matter and clay content of top and sub-soil respectively and the occurrence of gravelly layers, some 47% (r^2=0.47) of the total variation in root starch being due to the effect of these profile characteristics.

These relations suggested the possibility of defining "position on slope" as the resultant of the three most outstanding profile characteristics of these slope soils, *viz.* clay and gravelly layers in the subsoil and thickness of the organic topsoil layer. However, the fact that the correlation coefficient between "position on slope" and sum total of soil scoring marks (r_{PT}=0.41) was not significant, whilst the partial correlations $r_{RP.T}$ and $r_{RT.P}$ (table 2) were both significant, would seem to rule out this possibility. On the other hand, the existence of a rather close relationship between subsoil texture and root-starch (r=0.514) and between "position on slope" and gravelly subsoil (r=0.495), notwithstanding the crude scoring system employed, would warrant a more detailed study of the changes in these soil properties on sloping land.

Discussion

The results of the three experiments will be discussed in relation to soil erosion, productivity gradients and experimentation techniques on sloping tea land in Ceylon.

The sloping to steeply sloping tea land of Ceylon consists of soils mainly derived from granitic and gneissic parent material of Archaean or Precambrian origin.

Soil erosion, caused by water as the active force of erosion, is not considered a serious problem (Tolhurst, 1957) under the plantation system of tea cultivation in Ceylon. However, sheet erosion, *i.e.* the more or less even removal of soil in thin layers over an entire segment of sloping land, has been observed to take place on tea land, when it was exposed (a) after pruning and the removal of prunings, (b) after uprooting of tea or Guatemala grass prior to replanting with tea, or (c) during the first year or two after replanting with tea. The occurrence of this form of water erosion was also conspicuous from the gradual change in colour of the land from dark to light, as the removal of the dark top soil exposed the lighter coloured subsoil. Such a change in colour as the result of sheet erosion has often been claimed (Bennett, 1939) to be accompanied by a progressive decline in yield.

A form of water erosion, which has been observed after intense rainfall on bare slopes prepared for replanting with tea, is rill erosion. It is more obvious than sheet erosion, as the run-off water tends to concentrate in rill-producing streamlets, which leave small incisions in the land by the cutting action of the water.(Elias, 1961).

Still another, and probably the most important, form of downhill displacement of soil is that caused by mass movement of soil. If this process is slow and inconspicuous, it is called soil creep; if it takes a more rapid form, it becomes apparent as land slides. Land movement, like earth slips, land slides and terracettes, are well known in the Ceylon tea regions. Terracettes, also referred to as "cattle terraces", "sheep paths" or "cat steps" are found on steeply-sloping grass covered, so called patna areas in Ceylon, their origin generally having been attributed entirely to the trampling of cattle. However, slumping of masses of soil only a few feet wide (very conspicuous along road cuttings) can also have been the cause (Bennett, 1939) of these hillside steps on patna land, as well as of a similar and common phenomenon in cultivated tea land, *i.e.* of the marked exposure of tea roots at the lower side of the bushes only. Land movement, as soil creep and slumping, must, therefore, be considered a major factor in the downhill migration of soil on sloping tea fields in Ceylon.

Judging by the depth of exposure of tea roots, the amount of soil transported down an average slope was estimated to correspond with a layer of a few inches in the course of, say, 80 years under a permanent plantation system of tea cultivation in Ceylon. Assuming that it takes weathering of parent rock centuries to build one inch of topsoil, the rate of denudation far exceeds the rate of soil production.

Since the soil, involved in the process of mass movement, will generally not be transported out of the region in which it was formed, as is the case with water and wind erosion, but will be deposited lower down the slope, the upper parts of slopes will gradually become shallower to the benefit of the parts situated lower down the slope. This process of denudation may accelerate itself, the more so the shallower the upper slope becomes. In other words, the effect of soil creep on soil depth may in itself become a cause for (increased) soil creep. For instance, it has been observed that drainage of slope soils underlain by a less water permeable subsoil layer of clay takes mainly place through the top soil, the drainage water running downwards in the transitional zone between top and subsoil. The shallower the topsoil, the quicker it will become saturated and the more favourable the conditions will be for soil creep. Further, if these slope soils are cultivated with tea, top dressings of fertilizers will contribute little to the amelioration of the subsoil, as they will be leached away through the topsoil rather than penetrate into the subsoil. In these circumstances, neither the physical nor the chemical characteristics of the subsoil will be favourable for root penetration, thus reducing the possibility of anchorage of top to subsoil by means of tea roots. This in turn will result in accelerated soil creep, shallower rooting depth and so on. As the eroded material will be deposited at the bottom of the slope, the colluvial soils will become progressively deeper and, therefore, probably also more productive. In fact, Joachim (1961) working in the low-country of Ceylon has shown that the highest yields are generally obtained in the lowest contours and the lowest yields in the highest contours. The results presented here showed that productivity gradients on sloping tea soils can indeed be very large, *i.e.* of the order of an increase in crop vigour of 300% over a distance of only 200 yards down the slope (see Figure 1).

In the light of these observations and the finding of a negative correlation between root-starch and subsoil clay (table 2), soil borings down to 4 feet were made in each of the 16 sub-blocks of the clonal trial at St Coombs (Figure 3 and 4).

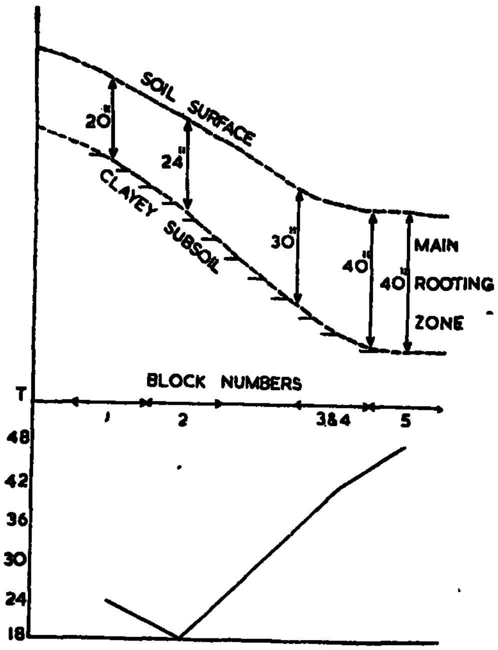

Figure 3.—The relation between position on slope, depth of rooting and subsoil clay, and tipping weight (T in kg) in blocks 1-5 of clonal trial (St Coombs). See also Figure 1.

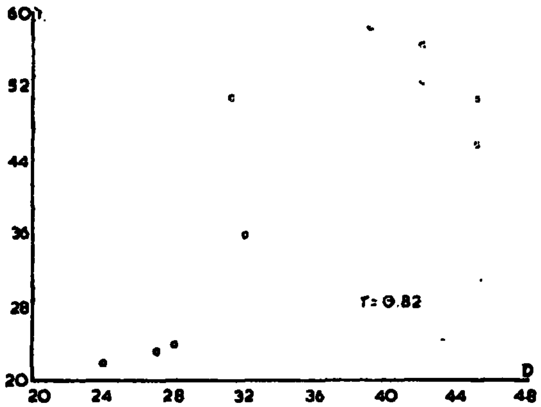

Figure 4.—The relation between rooting depth (D in inches) and tipping weight (T in kg) in sub-blocks 6-16 of clonal trial (St Coombs). See also Figure 1.

It will be seen from Figure 3 that there was a close relationship between tipping weight and the depth below the soil surface at which clay occurred in the 5 sub-blocks situated at the upper side of the road dividing the clonal trial area. The root-impeding clay layer would appear to be the primary cause for the productivity gradient along the slope.

Though rooting depth was also closely related (r=0.815; P=0.01) to tipping weight (Figure 4) in the remaining 11 sub-blocks situated below the road, the shallowness of the soil could not be attributed to the occurrence of a root-impeding clay layer in the subsoil. The productivity gradient along the slope and the corresponding variation in depth of rooting might have been due to the occurrence of slab rock or rock fragments at depths of 24" to 30" in the four upper most sub-blocks only. Furthermore, soil texture was lighter (loamy sand to sandy loam) in these 4 sub-blocks than in the remaining 7 sub-blocks (loam to clay loam) situated further down the slope.

These findings confirm also the one made in the root starch trial (see table 2) and show that depth below the soil surface at which clay or slab rock occurs, is an important characteristic of a soil profile which determines to a large extent soil productivity trends in sloping tea land. If the cause of such trends cannot be assigned to a root impeding horizon in the soil profile, rooting depth itself might indicate the effect of soil profile on the productivity of the land (Hasselo, 1962a).

In this connection it is of interest to note that Wijewantha (1964) found that the incidence of 'white root' disease, caused by *Fomes lignosus* (K.) Heim ex Pat. in young replanted rubber was significantly related to topography in the low-country of Ceylon. Infection by *Fomes lignosus* was 10% higher on the deep sandy loam soils on flat and undulating land than on the shallow heavier textured hill slope soils with a gradient of more than 10 degrees from the horizontal.

The results showed that soil type can be a very important factor limiting the yields of sloping tea land in Ceylon, the magnitude of its effect being much larger than that of many other known limiting factors in tea cultivation. It would warrant greater attention being focussed on soil profile studies and soil surveys, as the elimination of a limiting factor of this magnitude would greatly increase yields. Though improving the quality of a soil profile (Vink, 1962; Brzesowsky, 1963), is generally not economical (Hasselo, 1962a), the knowledge alone of the existence of a relationship between soil profile and yield might be of great economic importance. This may be illustrated by three examples.

Example 1: Manurial policy in Ceylon is generally based on the yield level of a field, the field being the smallest administrative unit for yield recording on an estate. It might be inferred from the results presented, that if the fields of an estate were mapped out on a topographical basis—which is generally not the case—the manurial policy would be more efficient. That is to say, if a field consists of both the upper and lower part of the same slope, the yield level of the entire slope (or field) will be intermediate between the high yielding lower and the low yielding upper part of the slope. The same holds for the amount of manure applied. Hence, if the upper half of the slope produced, say 5C0 lb made tea per acre per annum (p.a., p.a.) and the lower half 1,500 lb tea, then the mean yield of the entire slope or field will be 1,000 lb tea, whilst—on the basis of 10 lb N per 100 lb made tea—this field would receive 100 lb N p.a.p.a. In these circumstances, the upper half of the field received twice as much as the 50 lb N it ought to have had and the lower half 50 lb N less than the 150 lb N it should have had according to its yield level. Assuming, for argument's sake, that 50 lb N gives on average, a yield response of 10%, then the 50 lb N applied in excess on the upper slope must have produced 50 lb tea extra, whilst it could have produced 150 lb extra tea if it had been applied on the lower half of the slope instead. This numerical example shows that if fields are divided along rather than across the contour of a slope, which would result in a different and more efficient allocation of the total amount of fertilizer applied to the entire slope, a yield increase (of 50 lb made tea p.a.p.a. in this case) might be obtained without any extra expenditure on fertilizers.

Example 2: Replanting procedure. Suppose an upper slope soil produces 500 lb made tea p.a.p.a. and the lower slope soil 1,000 lb tea, and that the potential yielding capacity of a clone is 50% larger than that of the seedling tea with which the slope is planted. Then the upper slope soil would after replanting produce 750 lb tea and the lower one 1,500 lb tea. The choice whether to replant the lower slope instead of the upper slope, rather than *vice versa*, would boil down to the choice between (a) in the case of replanting the lower slope: having larger losses of crop during rehabilitation and immaturity, but larger gains once the replanted area has come into production, and (b) in the case of replanting the upper slope: having smaller losses during the rehabilitation period, but smaller gains later on. A simple calculation (assuming an unproductive period of 4 years during replanting) will show that it takes 3 years (or 7 years from the year of uprooting the old tea) before (a) has caught up with (b). After 3 (alternatively 7 years) proposition (a) will be more profitable than (b). Proposition (a) represents, therefore, an outlook based on larger profits in the long term at the expense of the short term gains made if proposition (b) is chosen (see also: Riminton, 1962).

Example 3: Choice of clone. The shallower soils of the upper part of a slope (Figure 3) will restrict the volume of soil available for rooting, hence the amount of water that is available during periods of drought. In areas like Uva, this may become an important consideration when decisions have to be taken on whether or not to replant with higher yielding clones, and, if so, on the choice of the area to be allocated for replanting and the clone to plant it with. If it is decided to replant a sloping field with clonal tea in a region with a pronounced dry season, then the drought resistance of the clone to be chosen should be given more weight when planting the shallow upper slope soil than the deeper lower slope soil. On the other hand, if it is accepted that seedling tea is more drought resistant than clonal tea, then it would be advisable to replant the lower slope only.

These three examples show that the division of an estate into fields on a purely administrative basis might not necessarily or always be the most efficient way to cultivate or even manage an estate. In view of the occurrence of large productivity gradients along sloping tea land, it would seem warranted to have the fields of an estate mapped out on a topographical basis in such a way that the field boundaries are drawn across rather than along the slope.

Sen (1963) and Laycock (1955) investigated the efficiency of experimentation techniques in tea experiments. Sen, working on flat land in Assam, obtained a greater efficiency, when the plots were long and narrow, their length being parallel to the direction of closer planting (*i.e.* to the hedges). Laycock, working on sloping land in Nyasaland, concluded that narrow plots running up and down the slope were more efficient, presumably owing to the occurrence of large productivity gradients along the slope. The presence of productivity gradients along a slope might also be reduced from results obtained by Pearce (1959, unpublished information) who re-examined data collected by Eden (1931) in a uniformity trial with seedling tea. It appeared that the experimental error was larger when plots were combined to form blocks running down the slope than with blocks across the slope.

Application of the conclusions by Sen and Laycock to sloping land in Ceylon would mean that the hedges would run up and down the slope. In Ceylon, however, this is not acceptable in view of the established practice of contour planting for soil conservation purposes. On the other hand, narrow plots running up and down a contour planted slope, would suffer from operational disadvantages in the conduct of the trial, as the plots would then cover relatively many rows with relatively few plants in each row. The better solution for Ceylon conditions on sloping land would, therefore, seem to be the Latin square design; alternatively the randomised block design with blocks consisting of one row of plots only arranged along the contour. The slope gradient within the area of one block should be as uniform as possible, in view of increased soil heterogeneity owing to variations in slope gradients. (See also Joachim, 1961). Different slope gradients on the same or on different slopes facing different directions could be chosen for different blocks, in order to obtain as wide a range of environmental and soil conditions as possible. It is obvious that this would be achieved easier if the blocks are small. However, small blocks would limit the number of treatments available for investigation, unless the plots are also correspondingly smaller. Treatment differences of between 3% and 6% have been found to attain significance in field experiments with plots containing 9 and 36 clonal plants and replicated 24 and 6 times respectively (Pethiyagoda, 1963; Hasselo, 1964). This shows that a high degree of efficiency can be obtained in experiments with relatively few clonal plants per plot.

In conclusion, the productivity of a soil, as determined by its quality (Brzesowsky, 1963) rather than by its chemical fertility, was shown to play an important part in soil/crop studies on sloping tea land, both from the view point of relative efficiency of alternative experimentation and of crop management techniques.

Summary

Tipping weight and root-starch content of tea plants grown on sloping land in 3 different localities, were related to the plant's position on the slope. Plant vigour, so assessed, increased for plants situated lower down the slope, and amounted, in respect of tipping weight, to more than 1% for every yard down the slope, and in one case to 300% over a distance of only 200 yards down the slope.

The occurrence of productivity gradients along a slope was discussed in relation to soil formation processes on sloping land. The massive displacement of soil down the slope, in the form of soil creep, land slides, terracettes, etc., was considered to be the major factor for the development of soils of different potential productivity, the shallow soils on the upper or steeper part of a slope being much less productive than the colluvial soils at the bottom of the slope.

Shallowness of the soil was reflected by the shallow rooting system of the plant, its depth being determined by the occurrence of root-impeding clay and rocky layers in the soil profile.

Examples were given to show how the shallowness of upper slope soils through its effect on limiting the availability of water during dry periods and the quick leaching of fertilizers from the topsoil—could adversely affect the vigour of tea plants.

Finally, the implications were considered of the occurrence of large productivity gradients on sloping tea land in relation to the relative efficiency of alternative experimentation and crop management techniques in tea. In respect of the latter, the importance was stressed of dividing an estate into fields according to their position on a slope.

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