PART II.

PROBLEMS IN LAC CULTIVATION.

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The preceding general introduction to the researches undertaken at the Indian Institute of Science in connection with the lac industry will have shown the manifold nature of the problems involved. The present paper deals particularly with those concerning the cultivation of lac, which have emerged during three years of intensive study. It is only after preliminary experience of this sort that the most fruitful lines for definite scientific experiment can be laid down. It should be noted that many of the observations recorded concern particularly the three-brooded insect of Mysore, and may not hold good with other species of insect in other parts of India. The problems are considered somewhat in the order in which they naturally arise, viz., those concerned with (1) inoculation, (2) nutritional requirements of the insect, (3) the best methods of pruning host-plants, (4) the general physiology of the insect and the possibility of controlling the sex ratio, (5) the possible varieties of host-plants and their relation to the varying species of insect, and (6) the character and effect of parasites. Naturally these various questions are somewhat interdependent, but for convenience they will be dealt with in the above order.

1. *Inoculation.*—Successful inoculation should ensure that the highest possible percentage of larvæ in a given portion of brood-lac attach themselves to the host-plant, survive, and produce the largest quantity of good lac. In the first place, therefore, the brood-lac should be cut before emergence has begun, a shorter or longer time being allowed, according to the destination of the material. If it is to be inoculated on to trees in the same plantation it can be left uncut longer than if it has to be transplanted to other areas, or possibly to be sent several days' journey by train. The time taken for complete emergence depends upon temperature, and may be five or six weeks during the cold and rainy season or a fortnight in hot and sunny weather. These facts should be considered when brood-lac has to be transported.

Under uniform climatic conditions the emergence begins gradually, rises steadily to a maximum and then suddenly falls. The fixing of an exact date at which emergence is likely to begin is still more or less a matter of conjecture. Recent observations seem to show that it has some relation to the phases of the moon.

The quantity or brood-lac to be used for a given inoculation, its position and manner of attachment, will depend on the character and extent of the adjacent branches and twigs. The larvæ are capable of crawling up a maximum distance of 16 feet to find their food, and this fact can be made use of in inoculating tall trees, whose highest shoots are inaccessible.

The lac insect in its larval stage is phototrophic. It instinctively settles on the lower portion of an inclined shoot. It would be interesting to determine the exact nutritional value of the upper and of the lower portions of such inclined shoots. If a cut is made in the lower portion of the shoot the exudation of sap is much greater than in the case of a wound on the upper side of the same shoot. The individual lac-insect, growing on the under side, yields a larger quantity of resin and a greater number of larvæ than the insect growing on the lateral portion of the same shoot. From these facts it is easy to see that the insects will settle all round a vertical shoot, and such shoots are the best for inoculation.

The determination of the most suitable period for the inoculation of pruned trees, or trees with fresh shoots, is difficult. No standards at present exist by which it can be judged that the shoots are fit to receive the brood. If too young and tender, overcrowding of the larvæ may take place, with too rapid a drain upon the sap, and all the larvæ which may have settled on such a twig will die. On the other hand if the surface of the twig is overrun with suberised veins, the density of larval settlement may be uneconomically low, viz., not more than a hundred, instead of the thousand which may attach themselves to a square inch of a smooth tender twig. This problem should receive immediate study, as the mortality which sometimes occurs in the first few days after larval settlement is often largely due to the hardness of the shoot, the larvæ being unable to pierce the bark. In the case of an old and unpruned tree, containing a large number of dead and dying twigs, the mortality may be as high as 90 per cent. The hardness of the bark is different in different species of host-plants, and is dependent upon the silica content. Plants with highly siliceous barks are not suitable hosts for lac cultivation.

It has been observed that as the diameter of a twig increases, above a critical point, the mortality among the larvæ also increases, possibly owing to the increasing silica content, and increasing suberisation of the bark. Below the critical diameter there is again a rise in mortality owing to inadequate food supply. The latter mortality which may occur after a few weeks is generally due to malnutrition brought about through a variety of causes. One serious factor is the presence of borers in the host-plant, which attack nodal points with the result that the shoot on which the larvæ may have settled, begins to dry up, being unable to draw nourishment from the parent branch.

2. *Nutritional requirements of the insect.*—The above observations lead to the consideration of the nutritional requirements of the insect. It is evident that plants should synthesise the nutriment, and supply it through the shoots in a form available to the lac-insect. If the food material is in an unsuitable form the insects die of starvation. Thus in the old shoots of an unpruned tree the carbohydrates are stored mainly as starch granules which the insect cannot readily assimilate ; in the shoots of a pruned tree the carbohydrates are present as a mucilage which appears to be an ideal food for the lac-insect. Besides this mucilage or gum, tannin in some form appears to be a necessary requirement.

For the host-plant successfully to withstand the drain of nutrient materials resulting from continued cropping of lac, its own food requirements must not be neglected. Carbohydrates, it is true, result largely from photosynthesis, but pot-culture experiments (to be described in a subsequent paper) have shown clearly the importance of phosphatic manures, if good crops of lac and vigorous broods are to be maintained. On the strength of a number of analyses of brood-lac the following interesting data have been calculated. A heavy crop of lac from an acre of forest containing about 100 trees produces 5,000 lbs. of brood-lac at the rate of 50 lbs. per tree, i.e., reckoning in the fuel removed by the labourers in the course of pruning the trees. Such a crop removes from the soil : 93 lbs. of nitrogen, 82–87 lbs. of phosphorus (P_2O_5), 62 lbs. of potash (K_2O) and 28 lbs. of lime (CaO). This continuous and heavy depletion of the inorganic constituents of the soil, if not adequately replenished from time to time, will prove disastrous both to insect and host-plant. Indeed, as a result of this continued impoverishment of the soil at Doraisanipalya, and the consequent devitalisation of the host-plants, the plantation has been seriously affected by borers, the attack in many cases actually killing the tree.

The whole question of the nutritional requirements of a lac plantation opens a wide field of enquiry. It is evidently important to conserve as far as possible all refuse material such as twigs, leaves, lac-waste, etc., returning it to the soil after suitable treatment if necessary. The question of nitrogen fixation and conservation in the soil of lac plantations is worthy of careful study, especially the part played by fallen leaves and by root symbiotes of different kinds.

3. *The Pruning of Host-Plants.*—In order to produce the tender shoots which it has been shown are necessary for successful inocu-

lation, pruning of the host-plant is necessary. Very little exact scientific knowledge exists in regard to this operation. There is hardly any arboricultural practice concerning which there is a greater diversity of opinion, or in the application of which there is a greater diversity of procedure.

As already explained, the chief requirements of lac-production from a given host-plant is a framework of tender shoots, which should function as efficient food suppliers. This framework is not so easy to supply at will. It is a response to the varying conditions within the tree, of nutrition, age, vigour, food-supply, temperature, humidity, light-intensity and numerous factors relating particularly to the soil. It must, if possible, consist of vertically growing shoots in order to accommodate the largest number of insects. These shoots must also be uniformly distributed along the parent branch. A well distributed framework of young shoots utilises the maximum amount of available solar energy, and elaborates the greatest quantity of nutrient material. Light pruning induces such a distribution, while heavy pruning results in a thick cluster of shoots, crowding at the cut. A close study of the shoot-bearing habits of important host-plants in response to various severities and modes of pruning, is a task of immediate practical interest.

By a judicious application of various topiary practices, a tree can be trained to a desired form, high-headed or low-headed, open-centred or close-centred, flat-topped or pyramidal. From the standpoint of lac cultivation the important consideration of an adequate supply of sunlight to the shoots must not be forgotten. Other economic and perhaps aesthetic considerations come into play in choosing the ideal form for host-plants. Low-headed, open-centred and flat-topped trees facilitate the operations of inoculation, harvesting and incidental treatment. They economise labour and supervision, and minimise the risk to the labourer of serious falls, especially in times of high wind.

Pruning, apart from removing the dead and dying limbs, and training the tree to some desired form, profoundly changes the physiological condition of the plant. It is attended, not only with the mobilisation of stored material, but also with intensive elaboration of fresh material. The effect of pruning in relation to lac growth is different in different seasons. During each harvest, the crop-bearing trees are necessarily pruned at the same time. Since in Mysore there are nearly three crops a year, each of the areas harvested during the year represents an area pruned in a different season. For the March crop, pruning operations are carried out at the beginning of summer for the July crop, during the heavy rains, while a third pruning takes place in October, at the beginning of the dormant season, when growth is very slow. It is a problem of interest to compare the growth of shoots from host-plants pruned at various seasons, and also their nutritional value. Such data might explain the varying resin-producing efficiency of the insect during different seasons of the year.

It has been stated that pruning renders the plant susceptible to the attack of diseases and insects, e.g., borers, pruned casuarina trees in Florida proving an attraction to beetles.[1] It has, indeed, been noticed at Doraisanipalya that the tender leaves which appear as a result of pruning are infected by certain aphids and defoliators, especially at the beginning of summer. If, on the other hand, the shoots are sufficiently well developed, the leaves are free from these pests. It is evident, therefore, that it is wise to prune the trees at a season such that the shoots grow to maturity by the following summer, and so are able to resist attack.

The practice of pinching the growing tips of shoots after larval settlement is a species of pruning, and results in the production of thick and healthy lac, by the suppression of further shoot-growth and the diversion of available nutrient material in greater proportion to the growing larvæ. This practice of pinching the terminal buds of shoots should, however, only be followed when a sufficient storage of nutriment in the tree is assured. Thinning the tree by removal of branches which do not bear larvæ will have the same concentrating effect.

4. *General Physiology of the Lac-Insect.*—A true parasite, the lac-insect cannot go through its life cycle without the aid of a host. Its parasitism goes much further than merely tapping its food supply from the host; it becomes permanently attached to the host, remaining immovable once it thrusts its proboscis into a shoot. There is evidence that the insect does not exercise actual suction but makes use of the molecular forces of the plant to take its food. The parasitism is so complete that with minimum expenditure of energy, the insect obtains all that it needs for its existence, and as a consequence undergoes profound parasitic degradation, losing its organs of locomotion at the first moult and becoming in its adult stage nothing but a pear-shaped sac, hardly recognisable as an insect.

The rate of resin-secretion by the insect is slow at the beginning of its life-history, but after the completion of swarming by the males, and consequent impregnation, the rate is intensified. It is important therefore, that during this later period of rapid resin-production, there should be an unfailing and abundant supply of nutritive material to the insect.

[1] *Jour. Agri. Res.*, 1919, 16, 155.

Honey is excreted in large quantities by the lac-insect at certain stages of its life-history. The period of active excretion corresponds with the period of active resin-formation. It is probable that, as in the case of the honey-bee, where a relation exists between the rate of production of wax and of honey, there is also a relation in the case of the lac-insect between the secretion of resin and the excretion of honey.

The general chemical composition of the lac-insect can be ascertained by the analysis of a number taken together, and the enzymes taking part in their life-processes can be determined in their expressed juices, or, possibly in a 'fossil' state in the lac incrustation, but the minute anatomical and physiological study of an insect, whose length measures only a millimetre in its larval stage is a difficult and delicate problem.

It is further complicated by the intervention of yeast-like organisms, which exist in the lymph of the insect, as well as in the sugary excreta. These organisms appear to have a symbiotic relationship with the insect. In those species of lac-insect in which these organisms naturally occur, their presence is a sign of vigour and health, whilst their absence indicates disease. A diseased lac-insect is instead bacterially infected with micrococci, which invite study from the standpoint of maintaining a healthy brood. Instances have been observed where colonies of lac have been infected by these micrococci with fatal results. The insect does not develop, and the eggs which may have been formed begin to disintegrate under this infection. It is suspected that these organisms may be spread by winged pests and parasites.

The yeast-like organisms, above referred to, can be cultivated in prune agar, but they do not seem to give rise to alcoholic fermentation. They are absent in certain species of healthy lac-insect, viz., *Tacchardia minuta*, which secretes only a small quantity of a dark, hard resin, sparingly soluble in alcohol. It would seem possible, therefore, that in some way these organisms influence resin-secretion. The problem of their exact function affords material for much careful study, which may throw light, not only on the physiological processes of the lac-insect, but on similar symbiotic relationships among other insects.

In considering the physiological conditions necessary to the production of a good lac crop, it will be remembered that it is the female which not only provides the future brood but also builds up the maximum amount of resin. The resin produced by the male during its short life-history is less than one-hundredth that of the female. The problem of sex control of broods is therefore of vital practical importance.

The proportion of males to females in a brood depends upon a number of factors, many of which are unknown. The ratio varies with the species, with the season, with the hosts and the nature of the food with which the mother is fed. *Ficus* species has a larger number of males than *Shorea* in the same season. Broods grown on plants rich in phosphates and nitrogen give broods with a female preponderance. Temperature and moisture also influence the determination of sex. The monsoon-fed brood generally has a large proportion of males, so that the following crop is poor.

It has been observed that males usually crowd together at the terminal portions of the shoot, while the more succulent and nutritious basal portion is colonised mainly by females. Larvæ that come out first occupy the best portions of the twig. Mr. Mahdihassan has made the interesting observation that the first batch of larvæ which hatch out are mostly females whilst those appearing later are chiefly males. This will explain why males are usually found crowded at the tops of shoots.

The question of sex ratio is naturally related to the actual number of larvæ produced per single mother cell. This again depends on the species of host and of insect, and on climate and cultural conditions. The number of larvæ produced by a single cell may be taken as a measure of the vitality of the brood. The following averages have been obtained when *Shorea* brood was cultivated on different host-plants during the June–October crop in 1921. The date of brooding was October 5, 1921 :—

Cajanus indicus	....	....	292	per	lac-cell.
Butea frondosa	....	....	426	,,	,,
Tectona grandis	....	....	445	,,	,,
Acacia concinna	...	....	460	,,	,,
Shorea talura	....	....	510	,,	,,

An Indo-Chinese species of lac-insect cultured on *Cajanus indicus* is said to give nearly 1,000 per lac-cell. The north Indian species, grown on *kusum* gave 575 larvæ per lac-cell. The proportion of males to females in each cell should be carefully studied, and those having a maximum number of females should be selected for propagation.

Besides the method of selection, the possibility may be considered of producing resistant broods by the crossing of two species of insects. If *Shorea* females, for example, are crossed by *Ficus* males, a brood may be expected, combining the hardy qualities of the *Ficus*, and the resin-producing qualities of the *Shorea* species. It may also be possible by careful observation and trial to evolve a race of insects immune to parasitic or microbial attack.

5. *Varieties of Host-plants.*—Various species of host-plants have been recorded from time to time, but it has not been sufficiently realised that their suitability depends upon the species of insect with which they are inoculated. Of the three species of insect occurring in Mysore, a wild brood found on *Ficus Mysoriensis* has been grown successfully on a great variety of host-plants. *Tacchardia minuta*, which was discovered by Mr. Mahdihassan on sandal and also on *Pongamia glabra*, can be grown on a number of trees, whilst the characteristic Mysore species, whose favourite host is *Shorea talura*, is very limited in its choice of host-plants.

Each species of insect also has its best and worst host-plants. On *Shorea talura*, for example, the Mysore species can be continued for generations without any deterioration, either in its vitality or in its resin-producing efficiency. If this *Shorea* brood is transferred to other hosts, like *Butea frondosa*, *Acacia concinna*, *Pithecalobium saman*, *Acacia Farnesiana*, etc., there is an initial fall in the vitality and resin-producing efficiency of the insect. The resulting broods, in many cases, are so weak that they cannot survive to another generation. If the resin-producing efficiency of the *Shorea* brood on *Shorea talura* in the rainy season is taken as 100, the proportionate figure on other host-plants in the same season is as follows :—*Acacia concinna* 95, *Butea frondosa* 90, *Acacia Farnesiana* 80, *Zyzyphus Jujuba* 70, *Pithecalobium saman* 50, *Cajanus indicus* 45.

Given the same brood, the order and index of efficiency of the host-plants varies with different seasons. In the rainy season, *Acacia concinna* produces a growth almost equal to the best on *Shorea*, whilst the other two crops show a poor growth. Given the same host-plant, the resin-producing efficiency during the same season varies with the species of insect. Thus the resin-producing efficiency of the *Ficus* species on *Pithecalobium saman* was nearly four times that of the *Shorea* brood on the same host-plant during the same season. These observations lead to the conclusion that the resin-producing efficiency of an insect is a variable, depending upon the species of insect, the host-plant and the season in which the lac is grown, other cultural factors being constant.

Two practical problems arise out of the above discussion :

1. Given a particular brood, what are the host-plants to be inoculated with maximum efficiency of resin-production ?

2. Given a host-plant, which species of insect should be chosen for inoculation ? These efficient combinations of season, brood and host-plant require to be worked out both from a practical and scientific standpoint.

Sylvicultural data with respect to the host-plants of lac are very fragmentary, while many of them are entirely unknown. It would be a useful task to collate the present knowledge regarding their habitat, flowering and seeding seasons and their shoot-bearing habits in response to pruning.

6. *Parasites.*—The study of the numerous parasites of lac is a wide problem of fundamental importance. Very often whole colonies of lac are destroyed by parasites, whose life-histories must be thoroughly investigated if they are to be brought under control. The *eublemma* moth, the most common and destructive of lac parasites, is to be met with almost all the year round. It is attracted, like most insects, by light, but specifically by the smell of lac-resin, as was shown by an experiment in which it was seen to lay its eggs on a dry stick smeared with shellac resin, although close by was a twig on which lac-insects had just settled. The moth is also attracted by the fermenting dye liquors, which are produced during the washing of seed lac.

Different species of lac-insect offer different degrees of resistance to parasitic attack. *Shorea* brood and *Kusum* brood, growing on *Cajanus indicus* are differently affected by parasites. *Kusum* brood, although growing by the side of the *Shorea* brood on the same shoot, is surprisingly free from any parasites. The number and kind of parasites vary with the season, the host-plant and the species of insect.

Another factor which has to be borne in mind in the investigation of parasites is that insects parasitic on other hosts may have a preferential affinity for lac when this is introduced into an area where they prevail.[1] In such cases alternative host-plants will have to be found, or methods of control devised.

Besides the parasites which make their attack directly upon the lac or the lac-insect, there are other associated forms of life which are attracted by the by-products of lac formation. Thus the honey, or saccharine excreta of the insect if allowed to accumulate, falls on lower shoots and leaves, giving rise to the development of a black fungus which has been described as a species of *Capnodium*. Although it does not directly attack the insect it may exercise a harmful effect by choking the breathing tubes and the anal aperture. Emergence also is checked as a result of the fungus stifling the larvæ within the mother-cell.

The excreted honey is a source of attraction to ants and bees. Certain species of ants show actual affection for the lac-insects, pro-

[1] cf. Imms and Chatterjee, *Ind., Forest Mem.*, 1915, vol. iii, pt. 1.

tecting them against parasitic attack. Bees collect the honey and store it in their hives, of which a number may easily be found distributed throughout the lac plantation. It would be of interest to introduce domesticated bees into a lac plantation, with a view to collecting the honey secreted by the lac-insect.

From the foregoing account of the problems met with in lac cultivation it will be evident that there is a great need for nurseries of lac to be established in different parts of India, where the different species of lac-insect and host-plant can be scientifically studied under suitable climatic conditions, and comparative trials made with broods from other districts. A beginning of such work has been made at Bangalore, and the results obtained will be published from time to time as they accumulate.