MYCORRHIZA

B. N. Webster

The title of my paper may be new to some of you so I must hasten to define my subject. The word mycorrhiza means, by definition, " a fungus root," being derived from the two Greek words for fungus and root. I would like here to express the hope that the remainder of this paper will not prove to be " all Greek " to my listeners.

The study of living plants in both natural and man made environments, more particularly with regard to their interactions with other living organisms, is an increasingly important and popular aspect of botany. Of the many living organisms which can affect higher plants probably none are more important than those bacteria and fungi which inhabit the soil, particularly that soil around the root systems of growing plants, the rhizosphere. The activities of many of these "unpaid millions" in the breaking down of humus, and in the maintenance of nitrogen availability, are well known to many of you, and it is not proposed to discuss them. I shall discuss the part played by those particular soil fungi which form a more or less regular association with the roots of certain plants. Some authorities claim that all higher plants are affected.

Explanation of the two types of mycorrhiza

Two principal types of mycorrhiza may, for facility, be defined. In both of them the invading fungus and the host roots form a close and constant association. The first (Fig. 1), or *ectotrophic* type is characterised by the presence of a closely woven sheath (s) of fungus mycelium, (*i.e.*, fungus threads) which completely envelopes certain, usually specialised short roots, of the host plant. The mycelium penetrates the root tissues and forms a continuous net-work between all the cells of the root cortex (Hartig net.). Contact is also maintained with the soil, enabling the fungus to function as "absorbing organ" of the affected roots. Root hairs are usually lacking.

In the second (Fig. 2) or endotrophic mycorrhiza, as the term suggests, the fungus mycelium is found within the cells of the root cortex. It is a moot point whether significant contact is maintained with the soil from the point of view of absorption of nutrients, but in this type also a paucity of root hairs has been noted. The internal mycelium often carries characteristic organs such as the expanded vesicles of unknown function (v) and the branched structures, known as arbuscles (a) which appear to break down under the digestive action of the host cells. It is suggested that this *vesicular-arbuscular* type of mycorrhizal fungus relies much more upon the host, than upon the soil, for its food supplies.

The significance of mycorrhiza

Having described the morphological aspects of the two types of mycorrhiza, I will attempt to give a brief account of their proved significance.

Since 1881, the study of the ectotrophic mycorrhiza of forest trees, particularly of the conifers (pines, etc.) has led to the elucidation of many problems of afforestation. It was found in many areas that conifers could not be easily established on certain poor, sandy loam soils, deficient in humus. The classic English example of which is of Wareham Heath in Dorset where the late Dr. M. C. Rayner carried out a series of experiments on the establishment of conifers. Her first trials consisted

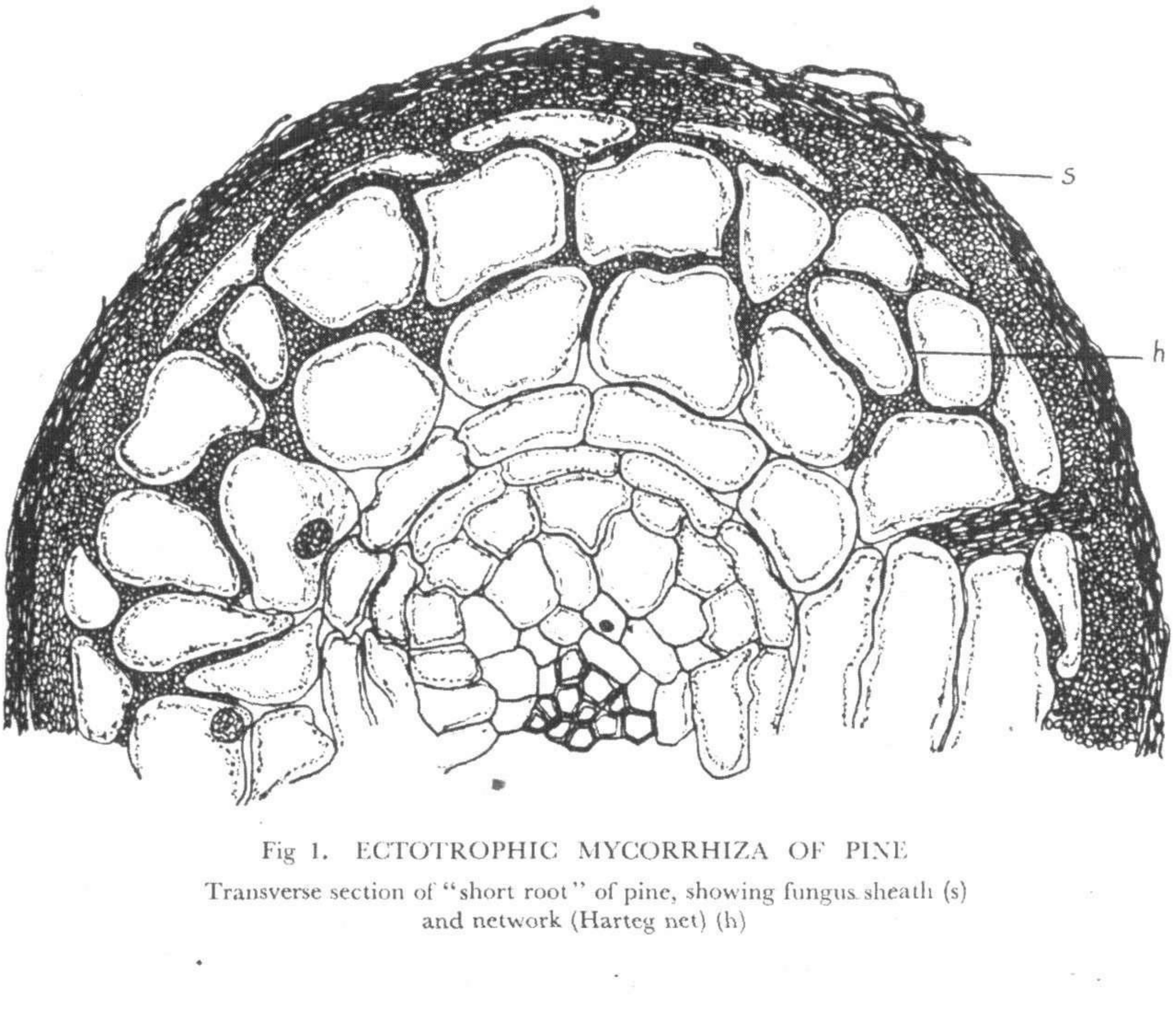

Fig 1. ECTOTROPHIC MYCORRHIZA OF PINE

Transverse section of "short root" of pine, showing fungus sheath (s) and network (Harteg net) (h)

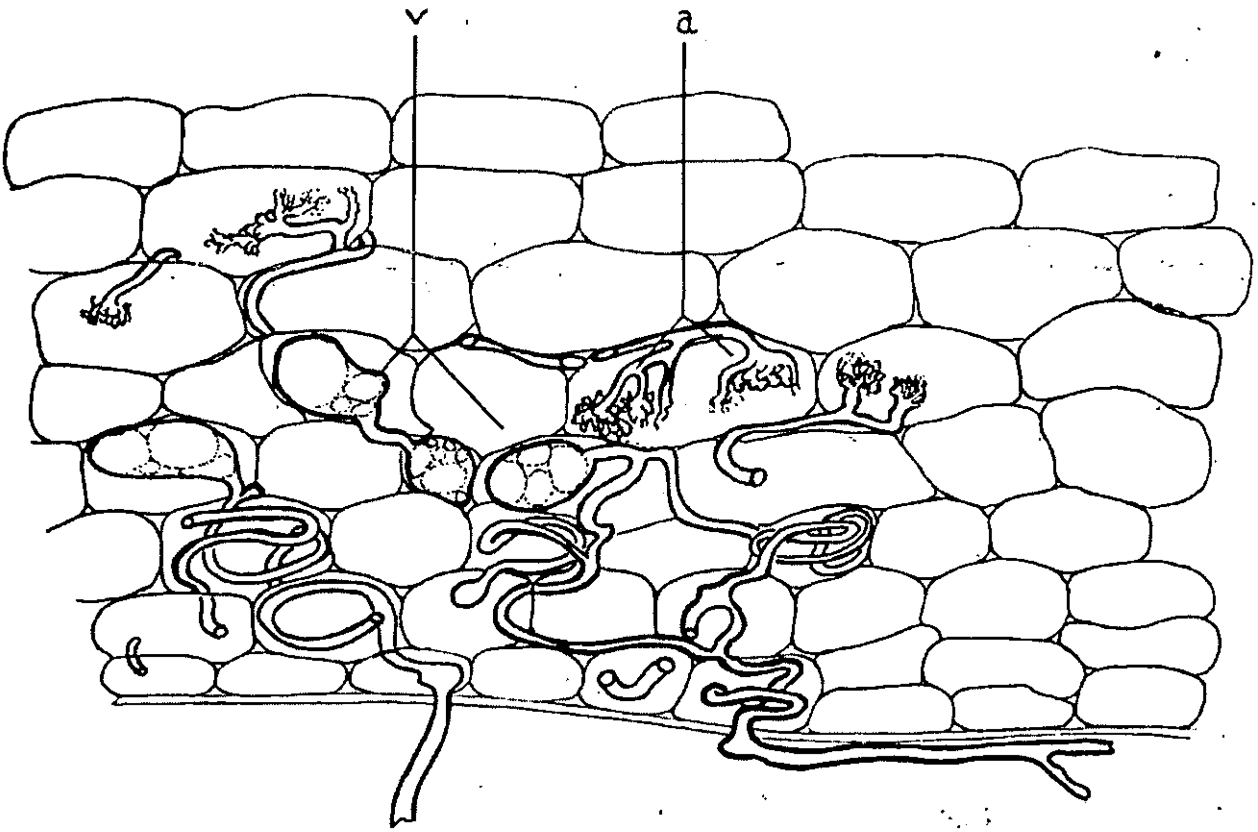

Fig 2. ENDOTROPHIC MYCORRHIZA OF. TEA

Longitudinal section of a fine feeding root of tea (T. R. I. Clone 2024) showing vesicles (v) and arbuscules (a), and mycelium penetrating the root. Semi-diagramatic.

of the introduction to the Wareham soils of small amounts of soil from good stands of pine in Sweden and Ireland. The applications were made to the seed holes at sowing time and representative plants were removed after 8 months, weighed and measured. It was seen that the plants grown in association with the " mycorrhizal " soils made considerably better growth than untreated plants.

TABLE I

Effect of inoculation experiments with mycorrhizal humus on growth of pine seedlings 8 months from sowing

Treatment	*Mean height*	*Mean weight*
Untreated Wareham soil	4.5 cms.	0.035 gms.
Swedish humus	5.5 cms.	0.065 gms.
Irish humus	7.0 cms.	0.077 gms.

Root examination confirmed that the treated plants possessed well developed mycorrhizas, whereas untreated plants showed aborted mycorrhizas or lacked them altogether.

On isolating the mycorrhizal fungus Dr. Rayner found it to be identical with that carried by the introduced humus. Although in many soils, such inoculation with a suitable endophyte has a lasting effect, it was found on Wareham Heath that the beneficial effect of inoculation was not continued during the second and third years.

As the lasting effect was not observed at Wareham, it was concluded that the soil was unsatisfactory for the growth of the fungus. An enquiry into the nature of the soil factors inhibiting mycorrhizal formation and growth, showed that, although the necessary fungus was present, the type of organic matter present in the soil was not suited to the mycorrhizal fungus. Applications of various different composts were made and it was ultimately found (after about 15 years) that the factors inimical to mycorrhizal fungi were anti-biotics probably produced by a species of *Penicillium* in the soil. Composting provided an organic food unsuitable for the growth of these antagonostic species, but eminently suited to the growth of mycorrhiza formers.

Work on the significance of endotrophic mycorrhiza has been principally confined to the two families Ericaceae (the heathers, etc.,) and the Orchidaceae. In both families the efforts of investigators have been largely directed to the examination of the effect of the associated fungus on seed germination and subsequent growth of the plants. For many years it was assumed that the majority of orchid seeds would not germinate unless the requisite fungus was present, and that adequate growth and flowering were impossible in the absence of the fungus. Orchid growers, therefore, maintain large culture collections of the specific fungi and orchid culture is a delicate and tedious business. In the last two decades, however, considerable information on the significance of the orchid fungi has been amassed, and several species of orchid have now been brought to maturity in artificial culture. It appears that the principal function of orchid fungi is the supply of plant vitamins, or accessory growth factors which the plant is unable to synthesise for itself, and the supply of suitable soluble nitrogen compounds and sugars. If these are supplied to the orchid in artificial culture then the presence of the fungi is redundant. In nature of course the fungi are still of primary importance to the orchid.

Similar conclusions were reached for heather and, in addition, certain of the heather fungi were shown to possess the ability to " fix " atmospheric nitrogen, *i.e.*, they assimilate free gaseous nitrogen and pass on to the plant the elaborated nitrogenous products either when digested by the root cells or by transmission through their walls.

A species of fungus morphologically distinct from those in heather and orchids has been demonstrated in a very wide range of higher plants, indeed some workers claim that it will ultimately be found in all families. It is the form found in tea and several other plantation crops, its significance in some of which I shall discuss.

Mycorrhiza in cocoa has recently been investigated in Trinidad. The morphological type found being close to that just described as vesicular-arbuscular. The investigation was confined to two cocoa estates, Las Hermanas and Tortuga, representing respectively a poor, and a very good type of cocoa, from the growth and yield aspect. Both were on similar soils and had received similar cultural treatment. Eight observations were made on representative root samples, taken at random, and the results indicate that the mycorrhizal density was very much higher in the poor, than in the better area, suggesting a possible pathogenic effect.

TABLE II

Mycorrhizal density in good and bad cocoa on soils of similar type.

Mycorrhizal roots %

Observation	*Las Hermanas (Poor cocoa)*	*Tortuga (Very good cocoa)*
1	86	57
2	80	63
3	86	57
4	86	63
5	86	53
6	80	63
7	80	57
8	70	50

The investigators claim no significance for these results, contenting themselves with the suggestion that much work should be done on the problem in view of the apparent absence of true parasitism.

Examination of the mycorrhiza of the citrus trees has, however, shown evidence of parasitism on the part of the fungus. The results of work in California, initiated by Rayner are shown in Table III.

TABLE III

Formation and development of mycorrhiza in citrus.

Manurial Treatment	Growth of fungus	Seasonal effect on fungus	Host reaction
Stable manure & green cover	Heavy at times. Dying out	Only during growing season of host	Defensive Digestion of fungus
No manure	Moderate but parasitic	Nil. Present all year round	Nil
Sodium Nitrate	Heavy parasitic	Nil	Breakdown of root cortex Trees unthrifty

Unfortunately, as is the case with most mycorrhizal investigations, no numerical results are given. Observations on the results of three manurial treatments have been condensed into the table as well as possible, and indicate that the possibility of the mycorrhizal fungus being a pathogen is high. Control is, however, achieved by adequate applications of organic manures. In unfertilised plots, or plots fertilised with sodium nitrate there is no doubt about the parasitic ability of the fungus. It may be claimed that the sodium was responsible for the root breakdown in the last treatment but the workers concerned were satisfied on various grounds that the fungus was responsible.

Similar results have been obtained in strawberry cultivation in Scotland, and in the growing of leguminous crops in the U.S.A. The same type of fungus has been invariably associated with poor soils and bad cultivation, and has, in each case been assumed to be pathogenic.

Mycorrhiza in tea

The known presence of mycorrhiza in tea dates back to 1901, when the organism which we now call *Rhizophagus theae* (Zimm.) Butler was first described under the name *Protomyces theae* as " of unknown significance." Tunstall at Tocklai described and figured in 1930 the same type of mycorrhiza with which we are dealing today in Ceylon. Its presence was again noted by Butler, over a long period in India, and by Sir Albert Howard and his associates in Ceylon tea.

The present work was started as the direct outcome of two independent observations. The first being that although tea soils produce adequate nitrates the tea bush does not appear to utilise them, and the second being an observed difference in density of root hairs between young and old tea, the latter appearing to have poorly developed root hairs. Examination of a random sample of tea roots from a normal field showed that about 75% carried a fungus within their roots. Small amounts of non-septate brown mycelium, were found running along the young white feeding roots, and in sections the points of entry could be clearly seen. No apparent pathological condition resulted. In the first sample examined the mycelium was somewhat scanty and no vesicles or arbuscules were seen, neither were there signs of digestion taking place. A second random sample was then taken from one of the T.R.I. Clonal rows, namely, Clone No. 2024. This proved a good guess as the fungus was found to be most luxuriantly developed, showing many vesicles, arbuscules and mycelial coils, and in addition showing the breakdown or digestion of the fungal hyphae.

Results of the examination of large samples of roots from good and bad areas are not yet to hand as the cutting of hundreds of sections takes rather a long time. Preliminary observations on the bad area suggest, however, that infection is slight. If this is so, it will be entirely contrary to the findings for other crop plants.

As to the possible significance of mycorrhiza in tea, it is much too early yet to form any conclusions.

The scope of the present investigations is wide and must, of necessity, be a long term programme. As a preliminary it is hoped that we shall be able to gain information as to the effect of various manurial treatments on the mycorrhizal fungus and whether these effects are reflected in the general behaviour of the bush. Secondly, the clone 2024 well known to many of you as a good rooter, rapid grower, high yielder and, in addition, quite highly resistant to blister blight must be closely examined to ascertain whether the observed fungus growth is peculiar to this clone, or merely a response to the treatment received by the clonal rows. This treatment, in addition to normal fertilisers has consisted of liberal applications of grasses as thatch.

Although we have shown that the ectotrophic type of mycorrhiza of conifers is of definite benefit to the plant, and that the endotrophic type is significant in orchid culture, there is no evidence of an endophyte such as we are dealing with being of any benefit to crop plants. On the contrary, those examples cited suggest a parasitic relationship and we must bear this fact in mind. We must also bear in mind the fact that in all cited cases of mycorrhizal association whether beneficial or parasitic, the application of organic materials whether as composts, stable manure or green stuff, has undoubtedly benefited the host plant. Wight at Tocklai suggests, without evidence it is true, that the varying responses of tea to nitrogeneou manures under-different shade levels is a direct response by the mycorrhizal fungus to light intensity. This is most unlikely, but does help to indicate the wide scope of the work.

If we can show for our fungus (*a*) sufficient soil connection for it to aid in absorption, (*b*) nitrogen fixation or elaboration or (*c*) the provision of growth substances by its breakdown, then we can adjust our cultural operations to benefit our fungus, and thereby our tea. If all or any of these is shown to be significant, then I suggest that our answer will lie in the provision of very much more organic matter to our soils.