a regular phenomenon in many crop plants, it appears likely, therefore, that intensive study of the soil conditions controlling its development may be a matter of practical importance to growers.

Although experimental research in the hands of a few specialists has yielded and continues to yield remarkable results for certain specialised groups, ignorance is still profound in respect to the significance and control of the widespread and apparently relatively unspecialised mycorrhiza known as the 'Phycomycete type'[1]. Recorded in an immense number of wild herbaceous species belonging to the most diverse families and from the most varied habitats, and also in a few trees, mycorrhiza of this kind has been observed in certain crop plants of economic importance; for example, strawberry[2], sugar cane[3], wheat[4], and the lychee[5]. It is of some interest, therefore, to place on record its existence in the genus *Citrus*; both in the sweet orange, *C. sinensis*, and the sour orange, *C. aurantium*, in the orchards of southern California. Previous records for the genus from Italy are fragmentary and unsatisfactory[6].

The roots of the cultivated orange are remarkably poor in root hairs, especially when grown in the neutral or alkaline soils of California. As observed in roots of trees from the experimental field plots at this Station, there is a regular and quite characteristic distribution of mycelium bearing large 'vesicles' in the young roots, involving inter- and intracellular infection with periodic digestion of the intracellular system of hyphæ and their contents.

Since oranges and other citrus fruits are cultivated under highly artificial conditions in California and elsewhere, it will be of interest to learn whether there is a similar type of root infection in the species used as stocks when growing wild in their native habitats.

The practical significance of the problem lies in the importance of nitrogenous manures in *Citrus* culture in California, where some form of this element is practically the only fertiliser employed. Experience has shown that nitrogen supplied as sodium nitrate or similar inorganic compounds gives poor results, whereas sodium nitrate treatments combined with stable manure or rapidly decomposable organic matter in the form of cover crops are highly beneficial.

No adequate explanation of these differential results has yet been offered, and the discovery of this type of mycorrhiza suggests that the organic materials supplied to the soil furnish appropriate food for the root fungus and provide the conditions requisite for root infection, a proportion of the metabolised products passing eventually to the root cells during the regular and extensive digestion of intracellular mycelium.

The application of pure culture methods to the problems presented by the mycorrhizal habit has proved the existence of mutualistic relations of fundamental importance in the economy of the vascular hosts, and older theories respecting the nutrition of mycotrophic plants must be reviewed and tested in the light of modern experimental methods. In the case of *Citrus*, carefully devised experiments and comparative observations on roots of trees subjected to different kinds of manuring in orchard plots should provide evidence of the correctness or otherwise of the hypothesis outlined above.

In view of the heavy cost of manuring in Californian orchards and the inconsistent responses shown by the trees, it is clearly of importance to ascertain whether different treatments and results can be related directly and invariably with the condition of the roots in respect to fungus infection.

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Number of Mendelian Factors in Quantitative Inheritance

IN a note in the current *Eugenics Review* entitled "Evolution by Selection", "Student" has directed attention to some statistical consequences of the inheritance of quantitative characters, in relation to the theory that these are due to the cumulative effect of a number of ordinary Mendelian factors.

"Student" refers in particular to the remarkable selection experiment carried out by F. L. Winter[1], in which a commercial variety of maize was exposed to mass selection from year to year in two diverging lines for high and low protein, and in two more for high and low oil content. For protein the initial value was about 11 per cent with a standard deviation of a little more than 1 per cent, but in the average of the last three years the mean of the high selection line is 16·82 per cent while that of the low selection line is less than half that value, namely, 7·53 per cent. The aggregate change produced by selection in both directions is thus 9·39 per cent, or more than nine times the original standard deviation.

With respect to variability, it may be noted that the high line now varies from 13·4 to 19·8 per cent, while the extremes for the low line are 5·7 and 10·5 per cent; so that the two lines are now separated by a considerable gap, and therefore cannot possibly have any single genotype in common. The variability of the low selection line has shown a slight tendency to diminish, and that of the high selection line a slightly greater tendency to increase, so that no general tendency to a decrease in variability ascribable to selection is to be observed; thus, there is no reason to think that the selective potentialities of the material have been appreciably exhausted in producing the great modification which has been brought about.

"Student" contrasts these well-substantiated facts with the belief, widely held among geneticists not so many years ago, that the selection of small differences (fluctuations) can only lead to unimportant evolutionary effects. They may also be contrasted with the oft-repeated statement that selection can do no more than select the best of the existing variety of genotypes, and with the commonly taught belief that the diversity available for selection is easily exhausted, from which it is inferred that evolutionary progress must wait upon the occurrence of mutations. It was, indeed, often represented as consisting in these occurrences.

The results obtained with oil-content have been even more striking; for the high oil line now contains nearly six times as much as the line selected for low oil content, and differs from it by more than

twenty times the original standard deviation. "Student" uses these data, together with reasonable estimates of the intensity of selection, to obtain an estimate of the least possible number of factors which must be postulated to obtain the results up to the date of the report; he concludes that at least 100–300 factors would be needed; and, taking into account the complete lack of evidence that selection is nearing its limit, considers that it is more probable that the actual number of factors is measured in thousands.

Estimates of the number of factors needed to explain quantitative inheritance are beset with considerable difficulty, and "Student" has admitted to me in correspondence that his calculation fails from over-simplification. Other well-established phenomena in maize, however, such as the flood of recessive defects revealed by every plant which has been used to found a selfed line, combined with the inevitable rarity of each of these defects, taken individually, in the population from which the foundation plant was selected, force one to the conclusion that all commercial varieties must be segregating in hundreds, and quite possibly in thousands of factors influencing the normal development of the plant. This emphatic experience, has, I believe, killed among maize breeders all those doctrines concerning the supposed inefficacy of the selection of minute differences, with which the teaching of modern genetics was at first encumbered.

It should be emphasised that the result of importance for evolutionary theory is not that the number of factors must be very large, thousands for example, rather than hundreds, but the direct demonstration that selection has the exact effects that selectionists have ascribed to it, without the limitations by which its action has been supposed to be restricted, on the strength of an early misapprehension as to the number and variety of the Mendelian factors exposed to its cumulative action.

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Fourier Analysis and Vowel Curves

IN NATURE of December 24, p. 965, Prof. E. W. Scripture discussed difficulties in applying Fourier analysis to recorded vowel curves, and he published two illustrations of the latter. The second of these, or at least what the corresponding curve would have been if the process of ground noise suppression had not been used in the recording, is strikingly similar to a curve I once drew up to illustrate complex modulation of a carrier wave in radio. The 'interior waves' correspond to the carrier wave, and the regular repetition or pattern corresponds to the so-called 'modulation envelope'.

This suggests that an alternative method of analysis, the applicability of which to a vowel curve similar to that published might repay investigation, would be to consider the vowel curve as that of a 'carrier note' undergoing modulation, the modulation being not necessarily sinusoidal but perhaps more complex. For example, the 'modulation envelope' of the published curve approximates to a saw-tooth form.

This method of analysis might not really be an alternative to Prof. Scripture's method, and might only be an alternative method of stating the latter. An artificial 'vowel curve' corresponding to saw-tooth modulation or other arbitrary modulation would make an interesting test of Prof. Scripture's and of other methods of analysis. Incidentally, such an artificial vowel curve could fairly easily be recorded and reproduced, and the electrical equivalent of it could be generated and reproduced directly without recording.

It may be worth while considering the bearing on these considerations of the fact that a modulated wave may be analysed into a carrier *plus* side-bands. A wave form approximating to a 'saw-tooth' modulated carrier can be constructed out of the carrier and a small number of side bands, all undamped waves. The general appearance of such a wave form would be similar to that of the vowel curve published, and therefore would afford (though in this case erroneously) just as strong grounds for holding that the wave form was inconsistent with analysis into undamped waves and that it required an analysis into damped waves.

The point which emerges from this is that Fourier analysis is not the only analysis into sinusoidal components. Consider a sinusoidally modulated carrier represented by $A(1+k\sin pt+\alpha)\sin\omega t$. If the carrier frequency, $\omega/2\pi$, is much greater than the modulation frequency, $p/2\pi$, the resulting wave form *seems* to be periodic at frequency $p/2\pi$, because the modulation envelope is periodic at this frequency. Close examination of the curve, or mathematical examination of the formula, shows, however, that the carrier waves in one cycle of the modulation frequency are situated differently with respect to the modulation envelope from those in another cycle, there being a phase difference. Unless ω is a multiple of p, the wave is not periodic at frequency p, and unless ω and p are commensurate there is no true period at all. Fourier's analysis is therefore not applicable, but this does not prove definitely that analysis into sinusoidal components is not possible.

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Photography of Faint Transient Light-Spots

PROF. H. HARTRIDGE in his letter in NATURE of January 21, expresses the need for "A lens having a numerical aperture of 0·8 or 0·7, a focal length of 25–50 mm. and adequate definition on the film over an area of 3–5 mm." It is perhaps not commonly noticed that a Mangin lens-mirror out of a motor-car headlight has just about this specification. I have used such a mirror to photograph a cathode ray oscillogram. The definition, though not what one would desire, was yet good enough to be useful.

Apparently there is no other commercial type of optical system that has both the large numerical aperture and the long focal length required, together with passable definition; but I should be glad to be corrected. The tiny image of an achromatic substage condenser was spoilt by scattering in the emulsion.

Some Mangin mirrors are purposely made with considerable spherical aberration on the axis, of a type thoroughly described by A. C. W. Aldis[1]. This aberration can, I find, be very simply corrected by placing a block of glass, having plane parallel faces,