AN INVESTIGATION OF THE MUCORALES IN THE SOIL.

By

Dr. M. E. Campbell.

Since the end of the nineteenth century, the bacteria, algae, protozoa and other invertebrate animals of the soil have been intensively studied, but until recently the soil fungi were almost entirely neglected in this country.

The present investigation was initiated during the summer of 1935 at the suggestion of Dr. Malcolm Wilson. The work was undertaken with a view to discovering what species of the Mucorales are present in the soil in Scotland and also to ascertain whether soil conditions have any influence on their distribution and ecology.

This first study revealed twenty-three species of the Mucorales occurring in seven soil types and from these results it has been shown that there is no specific distribution in the soils investigated.


The work is still largely of a systematic nature and until considerably more is known about the species which are liable to be found little work on their function in soil microbiology can be attempted.
During the summer of 1933 a visit was paid to Switzerland and advantage was taken of the opportunity afforded to collect soil samples from that country, and to compare the species isolated with those already obtained. So far, the following species have been isolated:


*Mucor javanicus* Wehmer - Isolated from soil of pinewood at 2000 feet altitude. No previous isolations from the soil. Zygospores have been found in pure culture and the species is heterothallic. There is only one previous record of zygospore formation.

*Piptocenhalis fusispora* van Tieghem - Parasitic on *Mucor* sp. Previous records from France and Holland.

*Rhizopus* sp. - Homothallic. Isolated from soil of pinewood at 2000 feet altitude. This is the first isolation of a homothallic species of *Rhizopus* from soil. Smith (1933) has described a homothallic *Rhizopus* under the name of *Mucor sexualis* which was isolated from a rotting strawberry at Cambridge and Naumov (1916) recorded a homothallic form obtained from the fruit of *Arctocarpus* sp. which he called *Rhizopus artocarpi* but his description is vague and it seems doubtful whether he was dealing with a monospore culture. Furthermore Weimer and Harter (1921 - 23) in a series of experiments on the rotting of sweet potato in America made use of a culture of *Rhizopus artocarpi* Raciborski but no description of this species or its origin are available.

Identification of further species from the above soil is still being carried out.

Since my first report in September, *Chaetocladium Jonesii* Berkeley & Broome originally found parasitic on/
on Absidia glauca Hagem, has been isolated in pure culture. This appears to be the first record of such a case.

Further work has been done on viability of species and the duration of Absidia cylindrospora Hagem in culture has been extended from 12 to 14 months while Mucor ramannianus Moeller has a duration of 8 months, and Dicoccum asperum Corda 25 months.

It is proposed to carry out work on the seasonal abundance of the positive and negative forms of the Mucorales in the soil using a common species such as Mucor hiemalis Wehmer. This species, which is easily identified, will be isolated monthly from soil of known fungus flora.

Little is known of the sexual behaviour of the Mucorales in the soil and a series of inoculation experiments have been devised to throw further light on this problem. In a preliminary inoculation experiment zygospores were formed in sterile soil but the conditions governing their formation and germination are not yet clearly understood. Once conditions suitable for the germination of zygospores have been discovered it will be possible to study sexual segregation in the Mucorales.
AN INVESTIGATION OF THE MUCORALES IN THE SOIL.

BY
MARIE E. CAMPBELL, B.Sc., Ph.D., Mycology Department, Edinburgh University, and Botany Department, St Andrews University.

[WITH THREE PLATES AND FIFTEEN TEXT-FIGURES.]
XVI.—An Investigation of the Mucorales in the Soil. By Marie E. Campbell, B.Sc., Ph.D., Mycology Department, Edinburgh University, and Botany Department, St Andrews University. Communicated by Dr Malcolm Wilson. (With Three Plates and Fifteen Text-figures.)

(MS. received April 6, 1938. Read May 2, 1938. Issued separately September 28, 1938.)

CONTENTS.

I. INTRODUCTION

The Mucorales have a wide geographical distribution and for seventy years they have been the subject of investigation both in Europe and in America. In this country, however, little research has been done on this group, the only workers being Bayliss-Elliott (1930) who has investigated the microflora of the Dovey salt marshes, Dale (1912, 1914) who examined the fungus flora of soil at Cambridge, and Brierley (1923, 1927, 1928) who has done considerable work on soil study. Although certain of the Mucorales were isolated by the last named, he was mostly concerned with the general methods of soil culture. The important quantitative technique was devised by Brierley (1927). Oudemans and Koning (1902) were the first to show the presence of Mucors in the soil. They examined the soil fungi in Holland and isolated two new species of Mucors. Möller (1903) investigated the fungi found in Pine mycorrhiza and obtained a further four new species. Hagem (1907, 1910) studied the morphology and physiology of seventeen Mucors from the soil of Norway, seven of which were new species. In 1908 Lendner published his "Les Mucorinées de la Suisse," an important contribution to the study of this group of fungi. A criticism which might be levelled at this work is that it is difficult to ascertain from it whether or not Lendner used pure cultures on which to base his descriptions. He merely states that "dilution methods used in Bacteriology were employed," no mention of monosporé cultures being made. Further important work on this group has been done by Korpatschewska (1909), Namy- slowski (1906, 1920), Naumov (1914, 1924, 1935), Ling-Young (1930), Johann (1932), Jensen (1912, 1931), and in the Kryptogamenflora der Mark Brandenburg (1935) Zycha gives a complete revision of the classification of the Mucorales. A survey of the geographical distribution of this group of fungi is found in the work of Niethammer (1935), while further classification has been done by Linnemann (1936). In America, Povah (1917) and Waksman (1916, 1917, 1922, 1927) have both added considerably to our knowledge of the Mucorales in the soil.

In Scotland, no work has been done on this interesting group. The present study.
was undertaken with the idea of finding out what species of the Mucorales are present in the soil in this country, and also to ascertain if soil conditions have any influence on their distribution.

II. Collection of Material and Cultural Methods.

In the summer of 1935 samples of various types of soil from different localities were obtained.

The methods of sampling were in the essentials those used by King and Doryland (1909) and Jensen (1912). A small trench about six inches across and five inches in depth was dug with a sterile trowel. After removing the soil from the face of this trench with a sterile scalpel, soil samples were taken at a depth of about three inches, as Waksman (1916) and Paine (1927) have both shown that there is a marked decrease below four inches in the number of soil fungi present. Sampling was done by inserting the mouth of a sterile test-tube horizontally into the soil and, after the desired amount of soil was obtained, the cotton-wool plug was quickly replaced. In soils such as peat, which do not allow the easy passage of the glass tube, the soil was removed with a sterile scalpel and transferred to a wide-mouthed tube.

The reaction of the soil was tested in most cases in the laboratory, as it was found by experiment that the pH of the sample did not change from that of the original soil provided that it was done as soon as possible after collecting.

In plating out the samples two methods were adopted, that of Hagem (1907) which consists of sprinkling a little of the soil over the surface of the Petri-dish containing nutrient medium. The second method is that described by Brierley (1927). A dilution of 1/20,000 in sterile water was made and then six poured plates were inoculated each with 1 c.c. of this soil suspension. As soon as the colonies began to show on the surface of the plates they were sub-cultured on to fresh media, thus giving pure multispore cultures. This precaution is necessary in order that the small forms may be obtained as well as the larger and stronger-growing forms.

It is essential for the accurate determination of species that monospore-cultures be used. For this reason a very little of the spore material was transferred by means of an inoculating wire to a tube containing about 10 c.c. of sterile water. The tube was next rolled between the hands to separate out the spores, and then a few drops of this suspension were inoculated on to the surface of a Petri-dish containing 4 per cent. malt agar. The spores were spread by means of a sterile glass rod and allowed to germinate. The inverted plates were examined under the microscope with the low power and the position of a single germinating spore marked with Indian ink. This spore was then cut out and removed to a fresh Petri-dish, where it was observed from time to time in order to be sure that only one spore was present.

Various media were tried such as Conn’s, Waksman’s and Cook’s No. 2 medium, but it was found that a very good standard medium was 2 per cent. agar with 4 per cent. malt, which has usually an acidity of pH 6. It was found that the addition of 5 per cent. peptone gave a more luxuriant growth, and in many cases the colour of the turf was darker.

As light affects the growth appearance, all the cultures were stored in a dark cupboard at a temperature of 17-19° C, which was found to be suitable for growth.

In making sub-inoculations, as little material as possible was carried over to the new medium, so that a normal growth would result and not the excessive growth obtained in cultures arising from a large mass of spores and mycelia. A normal growth is essential.
to the correct identification of species. After four to five days' growth the cultures were examined under a binocular microscope with the magnification of 100. At this magnification the growth habit is very clearly seen. All spores measured were freshly mounted in Laetic Acid Cotton Blue in preference to water, which is usually taken in by the spores in preparation for germination and thus tends to make them swell. In dealing with zygospore formation, it was found that it was necessary to keep the cultures under observation for at least four weeks, as some species appear to form the sexual organs only after a considerable period of growth. To prevent "staling" of the cultures the medium was changed, e.g. to oat agar, from time to time.

III. Distribution (Literature).

It is impossible to give a true picture of the fungal flora in its natural habitat, as our knowledge depends on cultural methods which are purely selective. Many species of the Mucorales have been stated to be peculiar to certain soil types or to certain plant communities. Möller (1903) claims that Mucor spinosus, Mucor Ramannianus, Zygorhynchus Moelleri and Mucor racemosus are peculiar to the mycorrhiza of Conifers; while Hagem (1907) found the following species associated in forest soils: Mucor Ramannianus, M. strictus, M. flavus and M. silvaticus. Absidia cylindrospora and Mucor hiemalis have been said by Pispek (1925) to occur only in alpine regions, but these two species appear to be among the most commonly occurring Mucors in all soil types in N. America, Europe and Greenland. According to Zycha (1935), M. mucello and the species closely related to it occur usually in cultivated soil, while Ling-Young (1930) claims that such species as Rhizopus nigricans, Chetocladium Jonesii and Circinella spp. owe their origin to the influence of man or beast.

On the question of soil reaction, Zycha says that the following fungi are usually present in acid soil: M. Ramannianus, M. spinosus and Zygorhynchus spp., whilst the alkaline-loving species almost all belong to the Mucor racemosus group.

In order to obtain a fair idea of the endemic microflora, Ling-Young (1930) says that soils should be examined from such localities as forests, peat-bogs and mountains which naturally remain untouched by man.

Coleman (1916) has shown that certain species of soil fungi differ in their response to environmental factors, and so it is not to be expected that there will be an even distribution of species in all soils. Generally speaking, however, the conditions prevailing above-ground are more variable than those present in the soil. The results of the present work tend to show that soil conditions do not affect the distribution of some of the species of the Mucorales to the extent that might be expected.

IV. Taxonomy.

In this work the term "variety" is used only when there is a distinct morphological difference between two forms of a species, while "strain" is used when two forms although morphologically identical show a physiological difference in growth, such as height of the "turf," colour differences, etc. As the two sexes of the heterothallic species are, with a few exceptions, usually indistinguishable one from the other, the term positive and negative "form" is used in preference to positive and negative "strain."

The Mucorales are a plastic group varying in appearance under different conditions
of growth. Within the species themselves there may be a number of different strains, e.g. *Mucor hiemalis* may have two to three strains (Price, 1927). Each of these strains has two separate sexes, which may react with the opposite sex of any one of the others. As a result of this multiple crossing a considerable number of varieties and strains may be formed, and the task of identifying species accurately in such a group becomes impossible. For these reasons the greatest difficulty is experienced in identifying Mucors with the existing keys. In fact, certain authors have described the same species under different names. Lendner (1908) used Fischer’s (1892) classification, dividing the group under three headings as follows: 

(a) Mono-Mucor or unbranched, (b) Racemo-Mucor or branching in racemes or corymbs, (c) Cymo-Mucor or branching in sympodial cymes. Hagem (1907) used much the same classification, his three headings being (a) Simple, (b) Cymose, and (c) Racemously branched sporangiophores. Branching alone, however, a very poor means of separating species as the branching may occur only in old cultures, while both cymose and racemose branching may occur in the same species. Lendner and Hagem placed the same species under different headings, e.g. *Mucor silvaticus* was placed by Hagem into the Racemo-Mucor group, while Lendner placed this species in his Cymo-Mucor group. Povah (1917) discarded these keys and gives a classification based on cultural characters on a standard bread medium. Unfortunately he deals with only eighteen species, so that his key is inadequate.

Zycha (1935) has completed a comprehensive study of the Mucorales and gives a workable key with which to identify the members of this group. Pure cultures of all the species were examined by Zycha on a standard medium, and then the cultures were compared with type cultures. The keys to the genera are fairly easy to use, but a criticism of the key to the species of *Mucor* might be made. In separating Section *Racemosus-Fragilis* from Section *Hiemalis*, Zycha makes use of a colour difference, which is of doubtful diagnostic value. The distinguishing characters for the *Racemosus-Fragilis* group are given as follows: “Growth slender, at first white, later grey or brown, sporangiophores strongly branched, sporangium wall breaking away or only slightly deliquescent,” while against that for the *Hiemalis* group we get: “Growth always white, yellowish or light grey, sporangium wall very deliquescent.” From the writer’s experience it was found that certain species of the *Hiemalis* group were at first white and later yellowish in colour. A more useful character was found, in this case, in the branching of the sporangiophores, which is not nearly so strong in the *Hiemalis* group as in the *Racemosus* group. Difficulty was also experienced in distinguishing between the species given in C. Section *Racemosus*. Here the difference between two groups is given as: (a) “Young growth white to yellow-brown,” or (b) “Young growth grey or grey-brown.” The difference between yellow-brown and grey-brown is not sufficiently constant. Zycha does not make use of the Ridgway Colour Code, and so his colours are difficult to determine. In separating *Mucor racemosus*, belonging to group (a) above, from *Mucor circinelloides* which belongs to group (b), the chlamydomspores were used in this work as a diagnostic feature. Those found in *M. racemosus* are nearly always barrel-shaped and are produced in great numbers, while in *M. circinelloides* they were found to be fewer in number and round in shape.

The taxonomy of the Mucorales was found to be extremely difficult, and in as many cases as possible the species isolated were compared with type cultures obtained from C. B. S., Amsterdam.
V. Distribution of the Mucorales within the Different Soil Types.

Soil No. 1. **Locality.**—Royal Botanic Garden, Edinburgh.

- **Soil Type.**—Rich Loam.
- **Soil Reaction.**—pH 6-6.
- **Species found.**—Mucor Ramannianus.
  - *M. hiemalis.* (Positive and Negative forms.)
  - *M. saturninus.
  - Zygorhynchus Vuillemini.
  - Absidia cylindrospora. (Positive and Negative forms.)

Soil No. 2. **Locality.**—Dalmeny, West Lothian.

- **Soil Type.**—Woodland.
- **Soil Reaction.**—pH 7.
- **Species found.**—Mucor hiemalis. (Positive and Negative forms.)
  - Absidia cylindrospora. (Positive and Negative forms.)

Soil No. 3. **Locality.**—Balerno, Midlothian.

- **Soil Type.**—Pine Wood.
- **Soil Reaction.**—pH 6-8.
- **Species found.**—M. hiemalis. (Positive form.)
  - M. silvaticus.
  - M. Mucedo.

Soil No. 4. **Locality.**—Longniddry, East Lothian.

- **Soil Type.**—Sand-dune.
- **Soil Reaction.**—pH 7-4.
- **Species found.**—Mucor albo-ater.
  - Mucor hiemalis. (Positive form.)
  - Absidia glauca.
  - Absidia cylindrospora. (Neutral form.)
  - Zygorhynchus Moelleri.
  - Chactocladium Jonesii.
  - Piptocephalis cylindrospora.

Soil No. 5. **Locality.**—Aberlady, East Lothian.

- **Soil Type.**—Salt Marsh.
- **Soil Reaction.**—pH 7-6.
- **Species found.**—Mucor racemosus. (Positive and Negative forms.)
  - M. hiemalis. (Positive and Negative forms.)
  - M. silvaticus.
  - Rhizopus nigricans. (Neutral form.)

Soil No. 6. **Locality.**—Bridge of Allan, Perthshire.

- **Soil Type.**—Heather Moorland.
- **Soil Reaction.**—pH 4.
- **Species found.**—M. silvaticus.
  - Mortierella sp.
Soil No. 7.  
**Locality.**—Ben Lawers at 2000 feet, Perthshire.  
**Soil Type.**—Peat Bog.  
**Soil Reaction.**—pH 4.8.  
**Species found.**—M. racemosus. (Neutral form.)  
M. microsporus.  
Zygorhynchus Vuillemini.

Soil No. 8.  
**Locality.**—Isle of Barra, Outer Hebrides.  
**Soil Type.**—Cultivated Soil.  
**Soil Reaction.**—pH 8.  
**Species found.**—M. spinosus.  
M. racemosus. (Neutral form.)  
M. hiemalis. (Positive form.)  
Circinella Sydowi.

Soil No. 9.  
**Locality.**—Isle of Barra, Outer Hebrides.  
**Soil Type.**—Sandy.  
**Soil Reaction.**—pH 6.  
**Species found.**—M. varians.

Soil No. 10.  
**Locality.**—Isle of Barra, Outer Hebrides.  
**Soil Type.**—Sand-dune.  
**Soil Reaction.**—pH 7.6.  
**Species found.**—M. circinelloides.  
M. racemosus. (Neutral form.)  
Circinella Sydowi.

Soil No. 11.  
**Locality.**—Isle of Barra, Outer Hebrides.  
**Soil Type.**—Peat Bog.  
**Soil Reaction.**—pH 6.  
**Species found.**—Zygorhynchus Vuillemini.  
*Absidia glauca.*

Soil No. 12.  
**Locality.**—Isle of Barra, Outer Hebrides.  
**Soil Type.**—Cultivated Potato Patch.  
**Soil Reaction.**—pH 7.2.  
**Species found.**—*Mortierella pusilla.* Forma typica.  
*Dictyococcus asperum.*

Soil No. 13.  
**Locality.**—Isle of Barra, Outer Hebrides.  
**Soil Type.**—Woodland.  
**Soil Reaction.**—pH 7.  
**Species found.**—M. hiemalis. (Positive form.)  
M. hiemalis. Form C. Ling-Young.

Soil No. 14.  
**Locality.**—Isle of Arran. At 2500 feet, Bute.  
**Soil Type.**—Peat Bog.  
**Soil Reaction.**—pH 6.6.  
**Species found.**—*Absidia cylindrospora.* (Positive and Negative forms.)  
*Mucor sp.*

Soil No. 15.  
**Locality.**—St Andrews, Fife.  
**Soil Type.**—Salt Marsh.  
**Soil Reaction.**—pH 7.4.  
**Species found.**—*Mucor fragilis.*
VI. Description of the Species.

*Mucor spinosus* van Tieghem, 1876. Text-fig. 1.

Growth is 6 mm. high on malt agar, at first white then a rich brown colour. On bread a black "turf" is formed. The sporangiophores (7.5–11 µ in diameter) are strongly branched, and the globose sporangia, which measure 50–60 µ, are brown in colour and strongly encrusted with crystals 2.5 µ long. The wall of the sporangium is deliquescent, leaving an oval to pear-shaped columella which may be from 17–47 µ long by 11–27 µ wide. *M. spinosus* is characterized by the presence of 1–3 spines at the apex of the columella. Zycha states that these spines are only present on the columella in old cultures, but in the form now isolated they were present in cultures after 3–4 days' growth as well as in old cultures. The dark brown spores are round in shape and 5.4–7.9 µ in diameter. Zycha gives the spore size as 4–7.5 µ. Chlamydospores, described by Zycha as being plentiful in old cultures, were not present in this form.

Heterothallic species. Zygospores were not found.

Isolated from soil No. 8—pH 8.


*Mucor Ramannianus* Möller, 1903. Text-fig. 2.

Growth is 1 mm. high on malt agar, rose to wine red in colour, finally a livid brown. The sporangiophores (2.5 µ in diameter) are simple, or with one branch. A cross wall is found 25 µ below each of the globose sporangia, which measure 20–25 µ in diameter. The sporangium wall is deliquescent, leaving a globose columella 4.7–5.4 µ in height. The spores are round, tinged with pink and from 2–3 µ in diameter. Chlamydospores 4.5–7.5 µ were plentiful. Heterothallic species. Zygospores were not found.

Isolated from soil No. 1—pH 6.6.

**Mucor racemosus** Möller, 1903. Text-fig. 3.

Growth on malt agar white, later deep brown in colour. The height of the “turf” is at first about 20 mm, but later the long sporangiophores die away, leaving a low brown “turf” composed of short, strongly branched sporangiophores each with a septum at the point of insertion of the branch. The globose sporangia are 45–68 µ in diameter and the sporangium wall breaks away leaving a basal membrane. When young, the columellæ are oval in shape, but in old cultures they are much twisted and shrivelled. They measure from 20–48 µ in height. The spores are oval in shape and are from 6–7.9 µ long with an average of 7 µ (50 measurements); a few 5 µ and 11 µ long were found. Zycha gives the spore size as 6–9 µ long, with a few spores 3 µ and 10 µ. Barrel-shaped chlamydospores, 15–19 µ in length, are very numerous in both the hyphae and the sporangiophores.

Heterothallic species. Zygospores (Pl. I, fig. 1) were found in multispore cultures. Both the positive and the negative forms were isolated and, with the positive and the negative type forms from C.B.S., Amsterdam, they formed perfect zygospores. After 14–21 days the zygospores are formed on the surface of the medium; they are small, 41–51 µ in diameter, and have a bright reddish brown colour. At first the surface of the zygospore is covered with a number of small irregular markings which finally merge together until they completely cover the surface. Chlamydospores may be present in the suspensors.

Zygospores have been described by Bainier (1884), who gives the zygospore size as 78–84 µ, Leger (1895), Sumstine (1910) and Saito Naganishi (1914, 1915).

Isolated from soil No. 5—pH 7.6. (Positive and Negative.)

No. 7—pH 4.8. (“Neutral” form.)

No. 8—pH 8.

No. 10—pH 7.6.


**Mucor circinelloides** van Tieghem, 1875. Text-fig. 4.

Growth on malt agar up to 2 cm. high, dense smoke-grey in colour. The “turf” is made up of tall and short sympodially branched sporangiophores; the short sporangiophores, which are more profusely branched than the long, may have circinate branching. The yellow to brown sporangia are from 40–90 µ in diameter. Zycha gives the sporangia size as 40–70 µ with a few 100 µ in diameter. The sporangia belonging to the tall sporangiophores have deliquescent walls, while in those belonging to the short sporangiophores the wall breaks away, leaving a basal membrane. The columellæ are round to oval, 18–40 µ in diameter,
AN INVESTIGATION OF THE MUCORALES IN THE SOIL.

and the regular oval spores are 4–6 µ long by 3–4 µ broad. Chlamydospores are present as in M. racemosus, but with the difference that when mature they are always round and 14–15 µ in length. Oidia are found 10 µ in diameter.

Heterothallic species. Zygospores were not found.

Isolated from soil No. 10—pH 7.6.


Mucor fragilis Bainier, 1884. Text-fig. 5.

Growth grey to brown on malt agar. Strong sympodial branching is seen in the sporangiophores. The sporangia are 45–55 µ in this form, while Zycha gives their size as 35–85 µ. The sporangia have deliquescent walls which leave a basal membrane, and the round to oval columellæ are 20–35 µ in height. The spores are regularly elliptical to cylindrical in shape and are twice as long as broad. In culture they were 5–7 µ long by 2.5–3.5 µ broad; according to Zycha they are 4–8 µ long by 2–4 µ broad.

Chlamydospores were not found. Heterothallic species. Zygospores were not present. Isolated from soil No. 15—pH 7.4. Previous isolation from soil: Germany (Zycha, 1935).

Mucor varians Povah, 1917. Text-fig. 6.

This species agrees with the original description given by Povah. The variation in spore size and in shape is diagnostic. The spores measure from 4–14 µ and may be round, oval, cylindrical or kidney-shaped, with a few bizarre in shape. Chlamydospores were found. They were not described by Povah, but Zycha mentions them in his description. Heterothallic species. Zygospores were not found.

Zycha failed to obtain zygospores when M. varians and M. hiemalis were contrasted, but this form gave perfect zygospores when grown along with the negative form of M. hiemalis (Pl. I, fig. 6). These zygospores resemble the normal zygospores of M. hiemalis but they are somewhat larger in size, being from 65–82 µ in diameter. Isolated from soil No. 9—pH 6.

Previous isolations from soil: N. America (Povah, 1917; Swift, 1929). Germany (Zycha, 1935; Linnemann, 1936).

*Mucor microsporus* Namysłowski, 1910.

This species agrees with the description given by Zycha (1935). The growth appearance resembles that of *M. hiemalis*, but it is not such a strongly growing form. The spore size and shape are important in the identification of this species. The spores are regularly cylindrical to elliptical in shape, 5 µ in length by 2-5 µ in breadth. Bright yellow contents were seen within the hyphae as well as in the columellae as noted by Zycha.

Heterothallic species. Zygospores were not found.

Isolated from soil No. 7—pH 4-8.


*Mucor hiemalis* Wehmer, 1903. Text-fig. 7.

Growth white to light grey on malt agar. The sporangiophores are numerous and branching is rare. The sporangia are at first light grey, later dark grey to brown in colour, and are 47-66 µ in diameter. The sporangia have deliquescent walls, and the round to oval columellae are colourless and 60 µ in height. In spite of their irregularity the spores are characteristic in appearance; they are long, oval or kidney-shaped, 4-9 µ in length by 2-4-5 µ in breadth, with an average of 7 µ by 3-5 µ (50 measurements). Lendner (1908) found a difference between the spore size of the positive and the negative forms. For the positive form he gives the average spore size as 7 µ, while the negative spore size is given as 5 µ. In this work no difference in the size of the spores of the two sexes was found.

Chlamydospores were not found.

Heterothallic species. Zygospores were found in multispore cultures after 4-5 days. Both the positive and the negative forms were isolated. The zygospores are dark brown in colour and they are covered with prominent markings arranged in irregularly shaped plaques, separated by clear furrows. In this form, which seems to correspond to Form A of Ling-Young, the zygospores measure 34-65 µ (Pl. I, figs. 2, 3). In Form C of Ling-Young, isolated from soil No. 13, a black band is seen on each side of the fusion cell (Pl. I, figs. 4, 5).

Although the two sexes of the form, which was isolated from soil No. 1, appear to be morphologically alike they show a physiological difference which is seen in the growth rates of the two sexes. At the end of three days the negative form produces a loose “turf” with numerous sporangiophores, while the positive form gives a compact “turf” on the surface of the medium with, as yet, very few sporangiophores. At the end of one week the growth of the negative form is about five times as tall as that of the positive form (Pl. II, figs. 7, 8). The flat growth of the positive now begins to resemble the negative, numerous sporangia having been formed, until at the end of two weeks the positive and the negative are identical in appearance. The growth of the positive form during the first two days was composed mainly of very large hyphae which covered the surface of the medium (text-fig. 7 b).
These hyphae are absent from the negative form.

This unequal growth of the two sex forms is best seen at 17° C. At 26° C. there is very little difference in the vigour of the growth.

The above results do not seem to agree with those of Blakeslee (1915) and Hagem (1907), who found that, in general, the positive forms of certain Mucors were more vigorous than the negative forms. Korpatschewa (1909), however, working with M. hiemalis, found that when grown on Raulin maltose medium the positive form was more vigorous than the negative form, while the opposite was the case when they were grown on Raulin saccharose medium. Temperature was also found by this same worker to have an effect on the vigour of the growth.

Positive and negative type cultures were obtained from Baarn, and although normal zygospores were formed with the two sex forms from soil No. 1 the type forms seemed to differ from them, both in morphology and in growth appearance. Equal growth was observed with the positive and negative type forms, and the colour was seen to be white to cream in contrast to the white to light grey of the form under investigation. The spores in the type cultures vary from 5-11 µ in length with a few 15 µ long. Chlamydospores were found in the cultures, and the zygospores, although having the same appearance as those described above, were larger, being 42-68 µ.

Hagem (1908) found that out of 52 cultures of M. hiemalis 26 were neutral. Ten forms were isolated by the present worker which at first, when contrasted with the positive and the negative type cultures, refused to form zygospores. Eventually, at the end of four weeks they had all formed zygospores with the negative type M. hiemalis, showing that they were all positive forms.

Isolated from soil No. 1—pH 6-6. (Positive and negative form.)

No. 2—pH 7.
No. 3—pH 6-8. (Positive form.)
No. 4—pH 7-4.
No. 5—pH 7-6.
No. 13—pH 7. " " (Form C. Ling-Young.)


*Mucor silvaticus* Hagem, 1907. Text-fig. 8.

This species agrees with the original description of Hagem (1908) and also with that of Zycha (1935). The regular cylindrical spores and the presence of chlamydospores and "giant cells" are the diagnostic characters.

Heterothallic species. Zygospores were not found.

Zycha failed to obtain zygospores on contrasting his forms of *M. silvaticus* and *M. hiemalis*. This form of *M. silvaticus* obtained from the present isolation formed perfect zygospores with the positive form of *M. hiemalis*. These zygospores are indistinguishable from the normal zygospores of *M. hiemalis.*

Fig. 8.—*Mucor silvaticus*. (a) Sporangiosphere; (b) columella; (c) spores; (d) chlamydospore; (e) giant cell. Camera lucida. x 450.
Isolated from soil No. 3—pH 6.8.
No. 5—pH 7.6.
No. 6—pH 4.


*M. albo-ater* is characterized by the height of the growth which is 30–80 mm. tall, by the large sporangia (200–400 µ) and the typical columnae and spores. The columnae are cylindrical to egg-shaped, and the irregular, oval to almost round spores are 5–15 µ long.

Heterothallic species. Zygospores were not found.

This species agrees with the description given by Zycha.

Isolated from soil No. 4—pH 7.4.


*Mucor Mucedo* Linné, 1762.

This species agrees with the description of Zycha (1935), and is characterised by the monopodial branching of the sporangiophores, which have large terminal and small lateral sporangia, gold to grey in colour. The walls of the sporangia are strongly encrusted with crystals, and on breaking away they leave a basal membrane. The columnae may be cylindrical to pear-shaped, and the regular spores are cylindrical to oval in shape and 8–12 µ long.

Heterothallic species. Zygospores were not found.

Isolated from soil No. 3—pH 6.8.


*Mucor saturninus* Hagem, 1910. Text-fig. 9.

Agrees with the original description of Hagem, 1910. *M. saturninus* is recognised by the two types of strongly branched sporangiophores. The short sporangiophores form a black “turf” on the surface of the medium, and the long sporangiophores are formed only after five to six days’ growth. The globose sporangia are at first grey, later black in colour, and the regular oval spores are 6–8 µ long.

Heterothallic species. Zygospores were not found.

Isolated from soil No. 1—pH 6.6.

Previous isolations from soil: America (Povah, 1917). Norway (Hagem, 1907). Germany (Zycha, 1935; Linnemann, 1936).

*Zygorhynchus Moelleri* Vuillemin, 1903. Text-fig. 10.
The growth, which is 6–10 mm., is at first white and then, as the zygospores are
formed, the colour changes to dark grey. The sporangiophores are branched sympodially and have dark grey to black sporangia, 14-50 μ in height. The columellæ are broad, flattened oval in shape, and the oval spores are 5-4-6-3 μ long by 3 μ broad.

Zycha gives the spore size as 4-4-5-7 μ long by 2-6-3-2 μ broad. Chlamydospores are present.

Homothallic species. The zygospores are 25-47 μ in diameter, with conical spines 3-5 μ long (Pl. II, fig. 11). In the species isolated by Namyslowski (1910) the spines of the zygospores were 4-6 μ long.

Isolated from soil No. 4—pH 7-4.


Zygorhynchus Vuillemini Namyslowski, 1910. Text-fig. 11.

This species was obtained from three different soils. The species isolated from soil No. 1 agreed with the type culture from C. B. S., Amsterdam, and with the description given by Zycha. The remaining two forms appear to differ from the type Zygorhynchus Vuillemini, as may be seen from Table I.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type culture C. B. S.</td>
<td>Loose fawn “turf”</td>
<td>5-6 mm.</td>
<td>Oval</td>
<td>4-4.5 μ.</td>
</tr>
<tr>
<td>Soil No. 1</td>
<td>Loose fawn “turf”</td>
<td>5-6 mm.</td>
<td>Oval</td>
<td>4-4.5 μ.</td>
</tr>
<tr>
<td>Soil No. 11</td>
<td>Close dark grey “turf”</td>
<td>1 mm.</td>
<td>Oval</td>
<td>2-6.5 μ, average 4-5 μ (50 measurements).</td>
</tr>
<tr>
<td>Soil No. 7</td>
<td>Close dark grey “turf”</td>
<td>5-6 mm.</td>
<td>Oval</td>
<td>2-6.5 μ, average 4-5 μ.</td>
</tr>
</tbody>
</table>

The zygospores of the above four forms are identical in appearance (Pl. II, figs. 9, 10). They are small, measuring from 29-45 μ in diameter, with spine-like protuberances which are 3-3.5 μ in length. As these spines are used as a diagnostic character to the species it has not been thought advisable to make a new species of the form isolated from soil No. 11. The difference in spore size, height of the growth and colour are constant characters, however, and so the form from soil No. 11 is considered to be a variety of the type Zygorhynchus Vuillemini. The third form, although morphologically identical with that isolated from soil No. 11, shows a difference in the height of the “turf” and so this form may be considered as a physiological strain.

Isolated from soil No. 1—pH 6-6.

No. 7—pH 4-8.

No. 11—pH 6-0.

Previous isolations from soil: N. America (Abbott, 1926; Waksman, 1916, 1917;
This form does not agree entirely with any of the descriptions given by Zycha for the species of *Circinella*. It resembles more closely the description of *C. Sydowi* than that of any of the other species, but differs in certain characters as may be seen from Table II.

**Table II.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Growth on Malt Agar</th>
<th>Height of Growth</th>
<th>Sporangia Size</th>
<th>Spore Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Circinella Sydowi</em> after Zycha</td>
<td>White to grey</td>
<td>5-7 mm.</td>
<td>100-150 µ in diam.</td>
<td>6-7 µ in diam., seldom 4-7 µ.</td>
</tr>
<tr>
<td><em>C. Sydowi</em> from soils Nos. 8 and 10</td>
<td>White to dark grey</td>
<td>2-5 mm.</td>
<td>44-95 µ in diam.</td>
<td>4-7.5 µ in diam.</td>
</tr>
</tbody>
</table>

Heterothallic species. Zygospores were not found.

In contrast with the other Mucors, this species is negatively heliotropic.

Because of the difference in the measurements of the sporangia and the spores this form is considered to be a variety of the type form of *Circinella Sydowi* Lendner.

Isolated from soil No. 8—pH 8.

No. 10—pH 7.6.

Previous isolations from soil: France (Ling-Young, 1930). Germany (Zycha, 1935).

**Rhizopus nigricans** Ehrenberg, 1820.

This species agrees with description given by Zycha (1935). When contrasted, however, with the positive and the negative type forms this form failed to produce zygospores and appears, therefore, to be a neutral form.

A constant difference was noted between this form and the type cultures when peptone malt agar was the medium. On this medium the type cultures produce a strong white to yellow "turf," which is mainly composed of vegetative hyphae with a few sporangia. In contrast, the neutral form gives a "turf" which is dark grey in colour due to the very large number of sporangia which are formed. This form is, therefore, considered to be a strain of *R. nigricans* Ehrenberg.

Isolated from soil No. 5—pH 7.6.


**Absidia glauca** Hagem, 1907.

Agrees with the original description of Hagem, 1907. This species is easily recognised by the greenish-grey colour of the "turf" which may be 20 mm. in height, by the short point at the apex of the semicircular columella (Pl. III, fig. 14) and by the characteristic round spores 2.4–4 µ in diameter.

Heterothallic species. Zygospores were not found.

Isolated from soil No. 4—pH 7.4.

No. 11—pH 6.

Absidia cylindrospera Hagem, 1907 and 1910.

This species agrees with the descriptions given by Hagem. A. cylindrospera is characterized by the white to grey-brown "turf" and by the columella with its long point at the apex, which is very easily broken off and may measure 4–10 µ in length (Pl. III, fig. 13). The regular cylindrical spores are 3.5–4.5 µ long by 2–2.5 µ broad.

Heterothallic species. Zygospores were found in multisporic cultures. Both the positive and the negative forms were isolated and, when contrasted with the positive and the negative type forms (C. B. S.), formed zygospores.

The zygospores are dark brown in colour. Hagem (1908) gives their measurements as 50–85 µ in diameter, but in the present culture the zygospores were found to be 40–60 µ in diameter. From one of the suspensors characteristic outgrowths are formed which encircle the zygospore (Pl. III, fig. 15). Although the two sex forms are morphologically identical, a slight difference in growth appearance has been noted. On malt agar the negative form becomes darker in colour after 4–5 days' growth, while the positive form does not darken in colour until after the 6th–7th day.

Isolated from soil No. 1—pH 6-6. (Positive and Negative forms.)
No. 2—pH 7.
No. 4—pH 7-4. (Neutral form.)
No. 14—pH 6-6. (Positive and Negative forms.)


Dicoccum asperum Corda, 1838. Text-fig. 12.

This species agrees with the description given by Zycha (1935), and is characterised by the two- to three-celled, oval spores, which have a dark brown warty exospore and resemble azygosporic. These spores, which are 10–15 µ broad, are not borne within sporangia but are carried on the ends of fine hyphae.

Isolated from soil No. 12—pH 7-2.
Previous isolation from soil: Germany (Zycha, 1935).

Chactocladium Jonesii (Berkeley and Broome) Fresenius, 1863 (text-fig. 18).
This species was found parasitic on Absidia glauca. The mycelium is deep grey in colour and the spore-bearing hyphae are strongly branched, each branch ending in a sterile point. The spores are borne singly and are from 7–10 µ in diameter. The walls of the spores are strongly crenated. Zygospores were not found.

Isolated from soil No. 4—pH 7-4.
Previous isolations from soil: Holland (Oudemans, 1902). France (Ling-Young, 1930).

This species was found parasitic on M. albo-ater. The mycelium is strongly branched, without runners or rhizoids, and light fawn in colour.
The spore-bearing hyphae have at the apex very strong dichotomous branching, which extends to one-fifth of their length. At the tip of each of these branches there is a single large cell known as the basal cell. This basal cell bears on it 2–3 spore carriers, each of which has 3–4 cylindrical spores which are arranged in a row. The spores are 3.5–4.7 µ in length and when they fall away a slight protuberance is left on the basal cell.

Homothallic species. Zygospores, which have been described by von Matruchot (1900), were found in cultures three months old. The zygospores measure from 25–33 µ in diameter and, with the suspensors, resemble a stirrup in shape (Pl. III, fig. 16). The exospore is thick but only slightly crenated, in contrast to that found in P. Freseniana which has a wart-like exospore. Gemmae are described by von Matruchot, but they were not found in the present cultures.

Isolated from soil No. 4—pH 7.4.

Previous isolations from soil: France (von Matruchot, 1900; Ling-Young, 1930).

**Mortierella pusilla** Oudemans, 1902. (a) Forma typica. Text-fig. 15.

Growth on malt agar, white. The sporangiophores have two to three branches arising from the same point. The sporangia are round with a deliquescent wall, and are from 25–30 µ in diameter. The round spores measure from 2.5–3.5 µ, and chlamydospores 7–10 µ long were found.

"Stielgemmen" and zygospores are unknown in this species.

Isolated from soil No. 12—pH 7.2.


**Mortierella tuberosa** van Tieghem, 1875. Pl. III, fig. 17.

This species was found growing on the surface of soil in the Botanic Garden at St Andrews. It agrees with the description given by Zycha (1935). In culture, sporangiophores were not formed, but the "stielgemmen" and chlamydospores were abundant.

Previous isolations from soil: France (Ling-Young, 1930).
VII. LONGEVITY OF SPORES AND MYCELIA.

From the present results it appears that the positive form of *Mucor hiemalis* has a greater distribution in the soil than the negative form. It is not known whether this species occurs in the soil in the form of mycelia alone or if both spores and mycelia are present. According to McLennan (1928), soil fungi are present in the soil almost entirely in the vegetative mycelial condition, while Jensen (1931) found this to be true for the genus *Zygorhynchus*. Isolations were made during the present work by the direct method used by Waksman (1916) for distinguishing between spores and vegetative mycelia in the soil.

As *M. hiemalis* was isolated after twenty-four hours by this method, according to Waksman this species must be present in the form of a mycelium. It may be noted that in the present investigation the spores of *M. hiemalis* germinated within seventeen hours and that the growth was visible to the naked eye by the end of twenty-four hours. In dealing with this species, therefore, the growth may be from vegetative mycelia or from spores.

The fact that there were more positive forms than negative obtained from the present isolations leads to the supposition that the positive mycelia or spores of the Mucorales are more resistant than the negative mycelia or spores. In order to test this supposition, *M. hiemalis* was chosen for the following experiment as it is a very widespread species. Four Petri-dishes, each containing 4 per cent. malt agar, were inoculated with spores of *M. hiemalis*, two with the negative form and two with the positive form. At the end of twenty-four hours all the spores had germinated. Growth was stopped by inverting the Petri-dishes over concentrated sulphuric acid in a desiccator. These cultures were composed of vegetative hyphae since the sporangia had not been formed. The same experiment was carried out with another set of Petri-dishes, only this time the growth of the fungus was allowed to proceed to sporangial formation before they were inverted over the concentrated sulphuric acid in the desiccators.

**Table III.**

*showing Resistance of Mycelia.*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-inc.:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25th March</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
</tr>
<tr>
<td>31st March</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
</tr>
<tr>
<td>25th April</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
</tr>
<tr>
<td>7th May</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
<td>Growth</td>
</tr>
<tr>
<td>20th May</td>
<td>Growth</td>
<td>Growth</td>
<td>No Growth</td>
<td>No Growth</td>
</tr>
<tr>
<td>27th May</td>
<td>Growth</td>
<td>Growth</td>
<td>No Growth</td>
<td>No Growth</td>
</tr>
<tr>
<td>10th June</td>
<td>Growth</td>
<td>Growth</td>
<td>No Growth</td>
<td>No Growth</td>
</tr>
<tr>
<td>10th August</td>
<td>No Growth</td>
<td>No Growth</td>
<td>No Growth</td>
<td>No Growth</td>
</tr>
</tbody>
</table>

In the Petri-dishes containing spores and mycelia growth occurred in both the negative and the positive forms up to a period of eleven months.

From the above experiments the following conclusions are drawn:—

(1) The vegetative hyphae of *Mucor hiemalis* are less resistant to drying than the spores.

(2) The positive hyphae are more resistant than the negative hyphae.

**TRANS. ROY. SOC. EDIN., VOL. LIX, PART II, 1937-38 (NO. 16).**
McLennan (1928) showed that soil fungi in general are present in the soil mainly in the mycelial condition, while from the present work it has been found that the positive mycelia of M. hiemalis are more resistant to drying than the negative mycelia. The explanation of the larger distribution of the positive form of *Mucor hiemalis* depends, therefore, on McLennan’s work, together with the results of the above experiment. This suggests that the positive form of *M. hiemalis* stands a greater chance of surviving in the soil than the negative form.

The following list of the duration in culture of certain species is not yet complete as the experiment is still in progress, but it indicates the resistance of the spores of some of the species.

**Table IV.**

*Duration of Species in Culture.*

<table>
<thead>
<tr>
<th>Species</th>
<th>Spores Germinate after:</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mucor spinosus</em></td>
<td>7 months</td>
</tr>
<tr>
<td><em>Mucor racemosus</em>, Positive and Negative forms</td>
<td>12 months</td>
</tr>
<tr>
<td><em>Mucor hiemalis</em>, Positive and Negative forms</td>
<td>11 months</td>
</tr>
<tr>
<td><em>Mucor Mucedo</em></td>
<td>9 months</td>
</tr>
<tr>
<td><em>Absidia cylindrospora</em>, Positive and Negative forms</td>
<td>12 months</td>
</tr>
<tr>
<td><em>Rhizopus nigricans</em></td>
<td>6 months</td>
</tr>
<tr>
<td><em>Zygorhynchus Moelleri</em></td>
<td>9 months</td>
</tr>
<tr>
<td><em>Zygorhynchus Vuillemin</em></td>
<td>9 months</td>
</tr>
<tr>
<td><em>Circinella Sydowi</em></td>
<td>7 months</td>
</tr>
</tbody>
</table>

Zycha (1935) says that the spores of *M. hiemalis* do not germinate after more than eight months. From the above results it is seen that both the positive and the negative spores of this species are capable of germinating after eleven months. This same worker states that the spores of *M. spinosus*, *M. Mucedo* and *Rhizopus nigricans* do not germinate after three months. This statement does not agree with the results as given in the above table, but it may be that the conditions under which these cultures were stored were more favourable than those of Zycha.

**VIII. Zygospor Formation and Hybridization.**

Out of the twenty-three species of the Mucorales isolated only three are homothallic, the remaining twenty species being heterothallic forms. Zygosporeres were, however, obtained in only three of these heterothallic forms. According to some workers, the nature of the medium and the temperature influence their production. Bainier (1884) states that “if *Mucor racemosus* be grown in an alcoholic decoction of plums during December, January and February one infallibly obtains an exaggerated production of zygospores.” The positive and the negative forms of *M. racemosus* from soil No. 5 were contrasted on an alcoholic medium of prunes during the month of February. The zygosporeres were not produced any more abundantly than when these forms were contrasted on 4 per cent. malt agar. Namyslowski (1920) claims that a medium rich in carbohydrates is favourable to zygosporere production, while one that is rich in nitrogen retards their formation. The positive and negative forms of *M. hiemalis* and *Absidia cylindrospora*, as well as the homothallic *Zygorhynchus Moelleri* and *Z. Vuillemin*, were grown on 2 per cent. peptone agar, but the resulting zygosporeres were as numerous as when these species were grown on 4 per cent. malt agar.
Light does not appear to affect the sexual activity, as zygospores are formed in equal numbers both in the light and in the dark.

In dealing with *M. hiemalis*, temperature was found to influence the formation of zygospores to a certain extent. When the two sex forms were contrasted at 26° C. very few zygospores resulted, but when the cultures were removed to 17° C. they proceeded to the abundant production of zygospores. Temperature did not influence the sexual activity of *Absidia cylindrospora*. Blakeslee (1904) says that “external conditions have only a secondary influence on the formation of zygospores and affect the various species differently.”

Among the Mucorales the loss of sexual activity appears to be common. Blakeslee (1915) notes that his *Mucor V.* showed much greater sexual activity than the type *M. hiemalis* from the C.B.S., Amsterdam, while later this same *Mucor V.* became weakened in sexual vigour. Hagem (1907) noted the same loss of sexual activity in one of his forms of *M. hiemalis*.

At the end of twelve months the present worker noticed that the positive and the negative forms of *M. hiemalis*, when contrasted, did not form zygospores in such large numbers as they had when freshly isolated. On contrasting these two sex forms, however, with the opposite sex forms of the type species of *M. hiemalis* from C.B.S., Amsterdam, zygospores were again produced in great numbers. It appears, therefore, as Blakeslee (1915) has shown, that adverse conditions do not have any lasting effect on the inherent sexual character of the species. A good example of “staling” was noted in dealing with *Absidia cylindrospora*.

Type cultures of this species were obtained from C.B.S., Amsterdam. According to Westerdijk (in lit.), the positive and the negative forms when contrasted fail to form zygospores in Amsterdam. However, on growing the two type sex forms on 4 per cent. malt agar, zygospores were produced in large numbers within 5–6 days. These two sex forms may be regarded as forms which have lost their sexual activity and become temporarily neutral, but, when grown again under more suitable conditions, they regain their sexual vigour.

Hybrid zygospores were formed between opposite sexes of different species of the same genus and also between species of different genera.

When *Mucor varians* and the negative form of *M. hiemalis* were contrasted a well-marked line was formed where the two species met which contained perfect zygospores (Pl. I, fig. 6). These resemble very closely the zygospores of *M. hiemalis*, but they are somewhat larger in size. Hybridization also occurred between *M. silvaticus* and the positive form of *M. hiemalis*. The zygospores appear to be identical with those of *M. hiemalis*. Limnemann (1936) also obtained perfect hybrid zygospores between *M. silvaticus* and *M. hiemalis*. This investigator found that these hybrids were somewhat larger than the zygospores of *M. silvaticus*, but, as the zygospores of these two species are very alike in appearance, it is difficult to distinguish between the hybrids.

Imperfect hybridization occurred by chance between *Absidia cylindrospora* and *Rhizopus nigricans* (Pl. III, figs. 18, 19). A monospore culture of the negative form of *Absidia cylindrospora* growing in a Petri-dish became contaminated by the positive form of *Rhizopus nigricans*, and in this manner imperfect zygospores were formed. No clear line of contact was seen where the hyphae of the two fungi met, and it was only after examination by means of a microscope that the zygospores were seen. They are very irregular in shape and in size. In no case were appendages found on the suspensors of the genus *Absidia*. Blakeslee (1904) noted hybridization between the above-mentioned genera, but the characteristic outgrowths from the *Absidia* suspensor were present, while this worker says that in hybridization production of gametes by both genera is very rare. Numerous unsuccessful attempts were made to produce these imperfect zygospores again, but it seems that the conditions for their
formation have not been reproduced, although the medium and the temperature were the same as in the first instance.

Various attempts were made to germinate single zygospores, but without success. It is known, however, that germination of the zygospores took place in a culture of *M. racemosus*. A culture of this species which contained abundant zygospores was stored for three months, after which there appeared to be a complete absence of zygospores within the culture. On examining the growth of the culture fragments of exospore were seen among the hyphae.

IX. Conclusion.

(a) Factors affecting Distribution.

The present knowledge of the distribution of the Mucorales within specific soil types is very incomplete. In this short study an attempt has been made to ascertain if there is any correlation between the soil conditions and the species of Mucorales isolated. For this reason soils of as widely different character as possible were examined, and fifteen soil samples, including seven different soil types, were taken.

<table>
<thead>
<tr>
<th>Table V.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distribution Within Specific Soil Types after Certain Authors.</strong></td>
</tr>
<tr>
<td>Species.</td>
</tr>
<tr>
<td><em>Mucor spinosus</em></td>
</tr>
<tr>
<td><em>M. Ramannianus</em></td>
</tr>
<tr>
<td><em>M. racemosus</em></td>
</tr>
<tr>
<td><em>Zygorhynchus Moelleri</em></td>
</tr>
<tr>
<td><em>M. silvaticus</em></td>
</tr>
<tr>
<td><em>M. Mucedo</em></td>
</tr>
<tr>
<td><em>M. albo-ater</em></td>
</tr>
</tbody>
</table>

The results in Table V show that the four species which Möller (1903) found to be associated in the mycorrhiza of Pinewoods were isolated from specific soil samples; not one of them was obtained from soil from coniferous woods.

*M. silvaticus*, although isolated from a Pinewood soil, was also found in soil from a Salt marsh and from a Heather moor. *Mucor Mucedo* was found in soil from a Pinewood which shows no sign of ever having been cultivated, certainly not for the last hundred years, while *M. albo-ater*, belonging to the same group, was found in soil from a Sand-dune which has never been under cultivation. Killian (1936) found *M. Mucedo* both in cultivated and in uncultivated soil from the Algerian plateaux. *Mucor racemosus* has a fairly wide distribution ranging from cultivated to uncultivated soil, but this species was not isolated from coniferous soil as found by Möller and Hagem. Werkenthin (1916) and Brierley (1928) were unable to find any difference between the species of soil fungi found in cultivated and in uncultivated soil, and from the present work no such specific distribution can be discerned for the Mucorales in particular. The present results, therefore, seem to add confirmation to what Brierley and Werkenthin have already shown to be the case for soil fungi in general.
AN INVESTIGATION OF THE MUCORALES IN THE SOIL.

The results also tend to show that all soils are not equally rich in the number of species found in them. Soils taken from a Heather moor and from a Peat-bog seem to contain fewer species of Mucorales in spite of the high acidity and humidity of these soils. Ling-Young (1930) noted a marked decrease in the number of species isolated from a Peat-bog, and Waksman (1916), working with soil fungi in general, has shown that the more fertile the soil the larger is the number of fungi present. It has been found impossible at this state of the work to draw any definite conclusions as to the richness of any one soil in species of Mucorales, as the number of soil samples and the lateral distribution of the species need to be taken into account. This can only be done after a much larger number of isolations have been made from the same localities than has been possible in the present study.

Although, as may be seen from Table VI, there are certain differences in the species which have been isolated from the specific types of soil, no well-marked microflora for them can be seen.

### Table VI.

<table>
<thead>
<tr>
<th>Species</th>
<th>Cultivated Soil 3 Localities</th>
<th>Woodland 2 Localities</th>
<th>Pine-wood 1 Locality</th>
<th>Salt-marsh 2 Localities</th>
<th>Heather Moor 1 Locality</th>
<th>Sand-dune 4 Localities</th>
<th>Peat-bog 3 Localities</th>
<th>No. of Times Isolated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucor spinosus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. Ramannianus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. racemosus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>M. circinelloides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. fragilis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. varians</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. microsporus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. hiemalis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>M. silvaticus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>M. albo-ater</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. mucello</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. saturninus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Zygorhynchus Moelleri</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Z. Vuillemin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Circinella Sydowi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Rhizopus nigricans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Absidia cylindrospora</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>A. glauca</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Didococum asperum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Mortierella pusilla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M. tuberosa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>No. of species</td>
<td>10</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>9</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Certain species such as *Mucor hiemalis*, *Mucor racemosus* and *Absidia cylindrospora* are, as Ling-Young (1930) and Jensen (1931) have pointed out, among the most commonly occurring species. It is seen from this table that these species have been obtained from practically all classes of soil.

A further question was whether the soil reaction has any effect on the distribution of the species of the Mucorales. Jensen (1931) states that he finds no relationship between
the species found and the soil reaction. The following species, however, are said by Zycha (1935) to be present in acid soil, namely *Mucor Ramanujanus*, *M. spinosus* and *Zygorhynchus spp.*, while, according to this worker, one finds members of the *M. racemosus* group in alkaline soils.

In the present work *M. Ramanujanus* was obtained from a soil with a pH of 6.6, *M. spinosus* from a soil with the reaction of 8, while *Zygorhynchus* species were isolated from acid soil with a pH of 4.8, and also in slightly alkaline soil with a pH of 7.4. *M. racemosus* occurred in acid soil, pH of 4.8, as well as in soil with an alkaline pH of 8. The present study suggests that certain species of the Mucorales, such as *M. racemosus* and *Zygorhynchus spp.*, are able to withstand a very wide range of hydrogen-ion concentration, whilst others, including *M. hiemalis* and *A. cylindrospora*, appear to have a more limited range, which was found to be from pH 6.6–7.6 in the case of the above two species.

In contrast with the higher plant communities, which are conditioned by the nature of the soil and by the climatic conditions, the Mucorales do not seem to be governed by these factors to the same extent. Indeed, Killian (1935) has shown that such species as *M. racemosus*, *M. Mucedo* and even *M. spinosus* are present in the soil of the Sahara, which has a maximum temperature and a minimum water-supply.

The idea of an ecological distribution of the Mucorales may be completely untenable once a sufficiently large number of soil samples and isolations from different types and localities have been made.

(b) Frequency of the Sex Forms in the Soil.

An attempt was made to ascertain with what frequency the two sex forms of the heterothallic species were present in the soil. As both the positive and the negative forms of *M. hiemalis*, *M. racemosus* and *Absidia cylindrospora* were isolated, the occurrence of their sex forms was investigated; *M. hiemalis* was obtained from seven soils, the proportion of the positive to the negative form being 25:4. In four out of these seven samples the positive form alone was isolated, and in the remaining three both the sex forms were present. This does not agree with the results of Hagem (1907), who found that in his forms of *M. hiemalis* the negative was more prevalent than the positive form, the proportion being 21 negative to 5 positive. Linnemann (1936) also finds that the negative of this species is more common than the positive form. The fact that the positive mycelia of this form of *M. hiemalis* seem to be more resistant to drying than the negative mycelia lends support to the results which the present worker has obtained (see pp. 427 and 428). *Absidia cylindrospora* was isolated on four occasions, the proportion of the positive to the negative form being 25:8. Here, again, the present results indicate that the positive form has the larger distribution in the soil. Linnemann (1936), however, dealing with this same species gives the number of isolations as follows: 4 positive, 7 negative and 3 neutral forms. Unlike *M. hiemalis*, a neutral form of *A. cylindrospora* was isolated which, although agreeing morphologically with the type cultures, failed to give zygospores when contrasted with them or with any of the positive and negative forms which were found. Out of four isolations of *M. racemosus* the positive and the negative forms were obtained only once, the remaining three yielding neutral forms. *Rhizopus nigricans* was isolated once, but so far it appears to be a neutral form. Although *M. silvaticus* was found in three separate soils there was no sexual reaction when the forms were contrasted one against the other, so that they must all be of one sex or be neutral forms. On contrasting *M. silvaticus* with the positive form of
M. hiemalis perfect zygospores resulted, suggesting that this form of M. silvaticus may be the negative one.

The occurrence of neutral forms among the Mucorales is frequent, these neutral forms being, however, merely potential sexual forms which, probably due to adverse environmental conditions, have temporarily lost their power of responding to the sexual stimulus. This neutrality may be induced in culture by growing at too high a temperature or by “staling,” as has been shown above (see p. 429).

In the present work the frequency of the sex forms in A. cylindrospora and in M. hiemalis are at variance with those of Hagem (1907) and Linnemann (1936), while in the remaining three species under consideration, namely M. racemosus, M. silvaticus and Rhizopus nigricans, the sex forms occur in a different ratio in each. From these results it is impossible to make general statements as to the distribution of the sex forms of the Mucorales in the soil.

(c) Separation of New Varieties.

The two forms of Zygorhynchus Vuilleminii which were isolated from soils No. 11 and 7 and the form of Circinella Sydowi obtained from soils No. 8 and 10 all differ considerably from their respective type species. In this study it has not been thought advisable to make new species out of these three forms, and so they have merely been designated varieties of the type species.

X. Summary.

1. Twenty-three species of Mucorales have been isolated from samples of seven soil types. Of these, twenty are heterothallic species, the remaining three being homothallic.
2. Descriptions of the species are given.
3. The following species have not been isolated before from soil in this country: Mucor hiemalis Wehmer, Mucor varians Povah, Mucor fragilis Bainier, Mucor silvaticus Hagem, Mucor albo-ater Naumov, Mucor saturninus Hagem, Circinella Sydowi Lendner, Rhizopus nigricans Ehrenberg, Absidia cylindrospora Hagem, Dicoccum asperum Corda, Chatoeladium Jonesii Berkeley and Broome, Piptocephalis cylindrospora Bainier, Mortierella tuberosa van Tieghem.
4. Zygospores have been obtained and described of Mucor racemosus Möller, Mucor hiemalis Wehmer, Absidia cylindrospora Hagem, Zygorhynchus Vuilleminii Namyslowski, Z. Moelleri Vuillemin and Piptocephalis cylindrospora Bainier.
5. Two new varieties of Z. Vuilleminii Namyslowski and a variety of Circinella Sydowi Lendner have been isolated and described.
6. Generally speaking, it has been found that the positive forms of the Mucorales have a larger distribution than the negative in the soil. The positive mycelia of M. hiemalis have been proved by experiment to be more resistant to drying than the negative mycelia.
7. A table has been given for the longevity in culture of certain of the species.
8. Conditions for zygospore formation are discussed.
9. Perfect hybrid zygospores were obtained in culture when Mucor varians and the negative form of M. hiemalis were contrasted and when Mucor silvaticus and the positive form of M. hiemalis were contrasted.
10. Imperfect hybridization occurred between the negative form of Absidia cylindrospora and the positive form of Rhizopus nigricans.
11. It has been shown that there is no specific distribution of the Mucorales within
the different soil types. Certain species such as *Mucor hiemalis*, *M. racemosus* and *Absidia cylindrospora* have been shown to be of very common occurrence, having been isolated from practically all types of soil.

12. The results tend to show, however, that all soils are not equally rich in the number of species of *Mucorales*. Soil from a heather moor and from a peat-bog contained fewer species than cultivated soil.

13. Soil reaction does not affect all the species of the *Mucorales* equally. It has been found that such species as *M. racemosus* and *Zygorhynchus* *spp.* are able to withstand a very wide range of hydrogen-ion concentration, while others (and among them are *A. cylindrospora* and *M. hiemalis*) have a more limited range.

The writer wishes to acknowledge her great indebtedness to Dr Malcolm Wilson for his generous assistance and constant interest throughout the work. Her thanks are also due to Professor R. J. D. Graham and to Dr J. A. Macdonald for helpful suggestions and advice.

Acknowledgment is due to the Carnegie Trust for the Universities of Scotland, part of the work having been done during the tenure of a Carnegie Research Scholarship. The author's grateful thanks are also due to the Trust for a grant towards the cost of the illustrations and tables.

XI. REFERENCES TO LITERATURE.


AN INVESTIGATION OF THE MUCORALES IN THE SOIL.


—, 1931. Ibid., vol. xlili, pp. 30-43.


Zycha, II., 1935. Kryptogamenflora der Mark Brandenburg, Pilz. 2, Mucor. neae.

XII. DESCRIPTION OF PLATES.

Plate I.

Fig. 1. Zygospore of Mucor racemosus. × 600.

Fig. 2. Young zygospore Mucor hiemalis. × 500.

Fig. 3. Mature zygospore Mucor hiemalis. × 500.

Fig. 4. Young zygospore of Mucor hiemalis form C., Ling-Young. × 500.

Fig. 5. Mature zygospore Mucor hiemalis form C., Ling-Young. × 470.

Fig. 6. Hybrid zygospore of Mucor hiemalis and Mucor varians. × 550.

AN INVESTIGATION OF THE MUCORALES IN THE SOIL.

**Plate II.**

Fig. 1 and 8. *Mucor hiemalis*, showing unequal growth of the positive and the negative forms. × 1.

Fig. 9. Zygospore of *Zygorhynchus Vuillemini*. Soil No. 7. × 900.

Fig. 10. Zygospore of *Zygorhynchus Vuillemini*. × 900.

Fig. 11. Zygospore of *Zygorhynchus Moelleri*. × 970.

Fig. 12. Sporangiophore of *Circinella Sydowi*. × 200.

**Plate III.**

Fig. 13. Columella of *Absidia cylindrospora*. × 450.

Fig. 14. Columella of *Absidia glauca*. × 400.

Fig. 15. Zygospore of *Absidia cylindrospora*. × 500.

Fig. 16. Zygospore of *Piptocephalis cylindrospora*. × 1000.

Fig. 17. Columella of *Mortierella tuberosa*. × 450.

Fig. 18 and 19. Imperfect hybrid zygospores of *Absidia cylindrospora* and *Rhizopus nigricans*. × 500.
DR. MARIE E. CAMPBELL: "AN INVESTIGATION OF THE MUCORALS IN THE SOIL."—PLATE I.
DR. MARIE E. CAMPBELL: "AN INVESTIGATION OF THE MUCORALES IN THE SOIL."—PLATE II.
Dr. Marie E. Campbell: "An Investigation of the Mucorales in the Soil."—Plate III.
<table>
<thead>
<tr>
<th>Vol.</th>
<th>Price to the Public</th>
<th>Price to Fellows</th>
<th>Vol.</th>
<th>Price to the Public</th>
<th>Price to Fellows</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>£2 2 0</td>
<td></td>
<td>XL.</td>
<td>£1 6 0</td>
<td></td>
</tr>
<tr>
<td>II.</td>
<td>0 9 0</td>
<td>0 7 0</td>
<td>Part 4.</td>
<td>0 10 0</td>
<td></td>
</tr>
<tr>
<td>III.</td>
<td>0 11 0</td>
<td>0 9 5</td>
<td>XLI.</td>
<td>1 1 0</td>
<td>0 15 9</td>
</tr>
<tr>
<td>IV.</td>
<td>0 16 0</td>
<td>0 15 0</td>
<td>Part 2.</td>
<td>1 9 6</td>
<td>1 2 0</td>
</tr>
<tr>
<td>V.</td>
<td>0 17 0</td>
<td>0 14 0</td>
<td>Part 3.</td>
<td>2 5 0</td>
<td>1 13 6</td>
</tr>
<tr>
<td>VI.</td>
<td>1 0 0</td>
<td>1 17 0</td>
<td>XXXIV. Part 1.</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>VII.</td>
<td>0 19 0</td>
<td>0 16 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>VIII.</td>
<td>0 18 0</td>
<td>0 15 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>IX.</td>
<td>1 5 0</td>
<td>1 1 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>X.</td>
<td>1 11 0</td>
<td>1 6 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XI.</td>
<td>2 2 0</td>
<td>1 11 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XII.</td>
<td>3 0 0</td>
<td>2 6 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XIII.</td>
<td>0 18 0</td>
<td>0 15 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XIV.</td>
<td>1 5 0</td>
<td>1 1 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XV.</td>
<td>1 11 0</td>
<td>1 6 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XVI.</td>
<td>2 2 0</td>
<td>1 11 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XVII.</td>
<td>3 0 0</td>
<td>2 6 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XVIII.</td>
<td>0 18 0</td>
<td>0 15 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XIX.</td>
<td>1 5 0</td>
<td>1 1 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XX.</td>
<td>0 18 0</td>
<td>0 15 0</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXI.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXIII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXIV.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXV.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXVI.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXVII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXVIII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXIX.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXX.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXI.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXIII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXIV.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXV.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXVI.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXVII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXVIII.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XXXIX.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
<tr>
<td>XL.</td>
<td>0 10 0</td>
<td>0 7 6</td>
<td>&quot;</td>
<td>2 2 0</td>
<td>1 11 0</td>
</tr>
</tbody>
</table>

* Vol. XXXV, and those which follow, may be had in Numbers, each Number containing a complete Paper.

Volumes or parts of volumes not mentioned in the above list are not for the present on sale to the public. Fellows or others who may specially desire to obtain them must apply direct to the Society. Fifty per cent. to be added to the prices of parts in the above list up to and including Vol. XXX. The publications of the Society are on sale through Messrs R. Grant & Son, Ltd., 129 Princes Street, Edinburgh, and Messrs Williams & Norgate, Ltd., 38 Great Russell Street, London, W.C. 1.
9. The Structure and Function of the Alimentary Canal of Eolid Molluscs, with a Discussion on their Nematocysts. By Alastair Graham, M.A., B.Sc., Department of Zoology, Birkbeck College, University of London. Communicated by Dr Charles H. O'Donoghue. (With Fourteen Text-figures.) Price: to Public, 5s. 6d.; to Fellows, 3s. 9d. (Issued May 24, 1938.)

10. On Some Undescribed Species from the Lower Carboniferous Flora of Berwickshire; together with a Note on the Genus Stenomyelon Kidston. By Mary G. Calder, B.Sc., Ph.D. Communicated by Professor J. Walton, D.Sc. (With Two Plates and Twenty-five Text-figures.) Price: to Public, 3s. 6d.; to Fellows, 2s. 9d. (Issued May 25, 1938.)

11. The Hairs of the Monotremata, with Special Reference to their Cuticular-scale Pattern. By A. B. Wildman, B.Sc., Ph.D., Wool Industries Research Association, sometime Ackroyd Memorial Research Fellow of the University of Leeds, and J. Manby, F.R.P.S., University of Leeds. Communicated by Professor James Ritchie, D.Sc., F.R.P.S. (With Seven Plates and Two Text-figures.) Price: to Public, 4s. 9d.; to Fellows, 3s. 6d. (Issued June 3, 1938.)


13. Differential Fertility in Scotland, 1911–1931. Part I. By Enid Charles, M.A., Ph.D., Leverhulme Research Fellow. Communicated by Professor Lancelot Hogben, F.R.S. (With Twelve Text-figures and Seven Tables.) Price: to Public, 1s. 6d.; to Fellows, 1s. 3d. (Issued August 5, 1938.)

14. An Analysis and Comparison of the Structural Features of Dactylotheca plumosa Artis sp. and Senftenbergia ophiodermatica Göppert sp. By Norman W. Radforth, M.A. (Toronto), Department of Botany, University of Glasgow. Communicated by Professor J. Walton, D.Sc. (With Two Collotype Plates and Two Text-figures.) Price: to Public, 2s. 3d.; to Fellows, 1s. 9d. (Issued September 28, 1938.)

15. On Rhamphodosis, a Ptyctodont from the Middle Old Red Sandstone of Scotland. By Professor D. M. S. Watson, F.R.S. Communicated by Dr C. H. O'Donoghue. (With One Collotype Plate and Five Text-figures.) Price: to Public, 2s. 3d.; to Fellows, 1s. 9d. (Issued September 28, 1938.)

16. An Investigation of the Mucorales in the Soil. By Marie E. Campbell, B.Sc., Ph.D., Mycology Department, Edinburgh University, and Botany Department, St Andrews University. Communicated by Dr Malcolm Wilson. (With Three Plates and Fifteen Text-figures.) Price: to Public, 4s. 6d.; to Fellows, 3s. 3d. (Issued September 28, 1938.)

[For Prices of previous Volumes and Parts see page 3 of Cover.]