HIGHER FUNGI IN SOILS OF COASTAL ARCTIC TUNDRA PLANT COMMUNITIES

BY

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Blacksburg, Virginia — Gary A. Laursen

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FOREWORD

A summary paragraph composed by the editors of Soil Organisms and Decomposition in Tundra, Holding, Heal, MacLean and Flanagan (1974), best describes the intent of the International Biological Program. They state:

> "The objective of the International Biological Programme (IBP) is an integrated study throughout the world on the biological basis of productivity and human welfare. Within the IBP Section on Terrestrial Productivity (PT), four major habitat types (or biomes) have been recognized, namely the Woodland, Grassland, Aridland and Tundra Biomes. In each of these biomes an analysis is being made of the structure of the ecosystems, the processes linking the various components and the factors which control the operation of the systems. The results of this analysis should assist in predicting the consequences of both natural and man-made environmental stress. . .".

Of the four biomes in the Terrestrial Section of IBP, my involvement has been with the Tundra Biome. Within the Tundra Biome three subprograms, the Producers, the Consumers and the Decomposers, fall within the Terrestrial Section. Brown and West (1970), in The Structure and Function of Cold-Dominated Ecosystems, state the direction for tundra biome research in Alaska.

> "The requirements for terrestrial ecosystem research in Arctic and Subarctic regions were dramatized by events immediately preceding and following the discovery of oil in 1968 at Prudhoe Bay. A keen awareness of these "fragile," cold-dominated ecosystems emerged as attempts to mechanically cope with them produced unsightly and destructive evidence of man's intrusions into a natural environment. The proposal to transport hot oil through a pipeline across the state of Alaska raised an additional series of crucial environmental questions.
>
> Until recently, physical and biological scientists had traditionally undertaken research more or less independently both in time and space. Where integrated research had been attempted, results were still presented by individuals, on discipline oriented subjects, and often in widely separated types of publications. The ecosystem concept and the methods of investigating, as a total system, the interrelationships of

all life forms with their physical environment, offered many advantages for the scientific pursuit of ecological assessment in the Arctic and Subarctic."

Within the framework of Tundra ecosystem research there were three overall objectives that were basic to the understanding of tundra, two of which were primary to my study. Those two were:

1. "To develop a predictive understanding of how the wet Arctic tundra ecosystem operates, particularly as exemplified in the Barrow, Alaska area."

2. "To bring basic environmental knowledge to bear on problems of degradation, maintenance, and restoration of the temperature-sensitive and cold-dominated tundra/taiga ecosystem."

It was the atmosphere of integrated research within the ecosystem research concept, coupled with the methods of investigation, that placed this study of soil fungi into the confines of the Decomposer subprogram. My objectives, stated in a later section, became only a portion of total decomposer effort. But, this effort was vital to the understanding of the tundra belowground ecosystem. It was important for the decomposition effort to know what microorganisms were in the soils, their population density and what roles they played in the total process of decomposition. The study of soil fungi was vital to this integrated biome research effort.

This effort has extended into four field seasons of work in the vicinity of Barrow, Alaska. During that time I have seen a great deal of Alaska, particularly Arctic Alaskan tundra, where my interests have spread to many ecological problems as they relate to fungi.

My interest and involvement in Arctic mycology came about as a

result of previous work done at the University of Montana's Biological Station on Flathead Lake. There, I spent four summers studying Rocky Mountain Biology, most of which was botanically oriented. I chose botany because of an interest developed during my undergraduate study. I also strongly sensed a need to become knowledgeable in one area of Botany. Previously developed interests were in lower plants, but the decision to focus on one specific group of plants had not yet been made.

During my second summer of support through an NSF fellowship, I was introduced to Mycology and to Dr. Orson Miller. It was in his introductory Mycology course that I first experienced the excitement of Montans's high country and learned that the study of fungi was not restricted to wet rotting logs. In fact, fungi were found abundantly in every major plant community we visited in Montana from the grasslands to alpine tundra. With the completion of Dr. Miller's course I knew where I wanted to focus my attention and where a great deal of expertise could be developed in one area of Botany, the study of fungi. I pursued and continued the study of fungi with Dr. Miller during subsequent years at the station where in 1970 I did a terminal Masters paper on the Fungi of Glacier National Park. This and many other factors led to an invitation from Dr. Miller to do advanced study in the fungi at VPI & SU. I considered this a once in a life time opportunity and quickly accepted the offer. A year later I was offered an opportunity to study fungi in Alaska. Not only was the thought of going to Alaska exciting, but to study in alpine and Arctic tundras meant fulfillment of another long held ambition.

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INTRODUCTION

The first field season of my involvement on the Arctic project with the U.S. International Biological Tundra Biome Programme began in 1971. During the second season, 1972, in depth considerations were given to the incorporation and refinement of certain techniques that allowed the answering of questions relative to the fungal biomass objectives as stated. Most objectives were designed for the integrated research approach within the U.S. International Biological Programme ecosystem study. The Tundra Biome efforts were conducted internationally within nine northern countries. The major research emphasis has been confined to 20 sites, 14 of which were within the Arctic Circle, 66° 30' N. Latitude (Fig. 1). Six sites in 4 countries were developed in alpine or coastal moor tundra south of the Arctic Circle (fig. 1).

In 1971 the initial and major thrust of the study of Arctic fungi in the U.S. Arctic centered around floristic studies of the higher fungi. Particular interest was given to the fruiting body and ecological distribution of basidiocarps and ascocarps. Considerations and decisions concerning the formation of plots for intensive and destructive sampling were made. It was visually apparent that several major plant communities were ecologically distributed throughout the patterned ground system of polygons. This led to the recognition of a moisture gradient and to the formation of an early hypothesis that primary productivity, and therefore decomposition rates by filamentous soil fungi, were dependent on the moisture gradient. It was necessary to know what the standing crop of mycelium

Figure 1. A location map showing the nine Arctic and Subarctic countries and their respective sites of IBP Tundra Biome activity in relation to each other, the North Pole and to the Arctic Circle, 66° 30' N. Latitude.

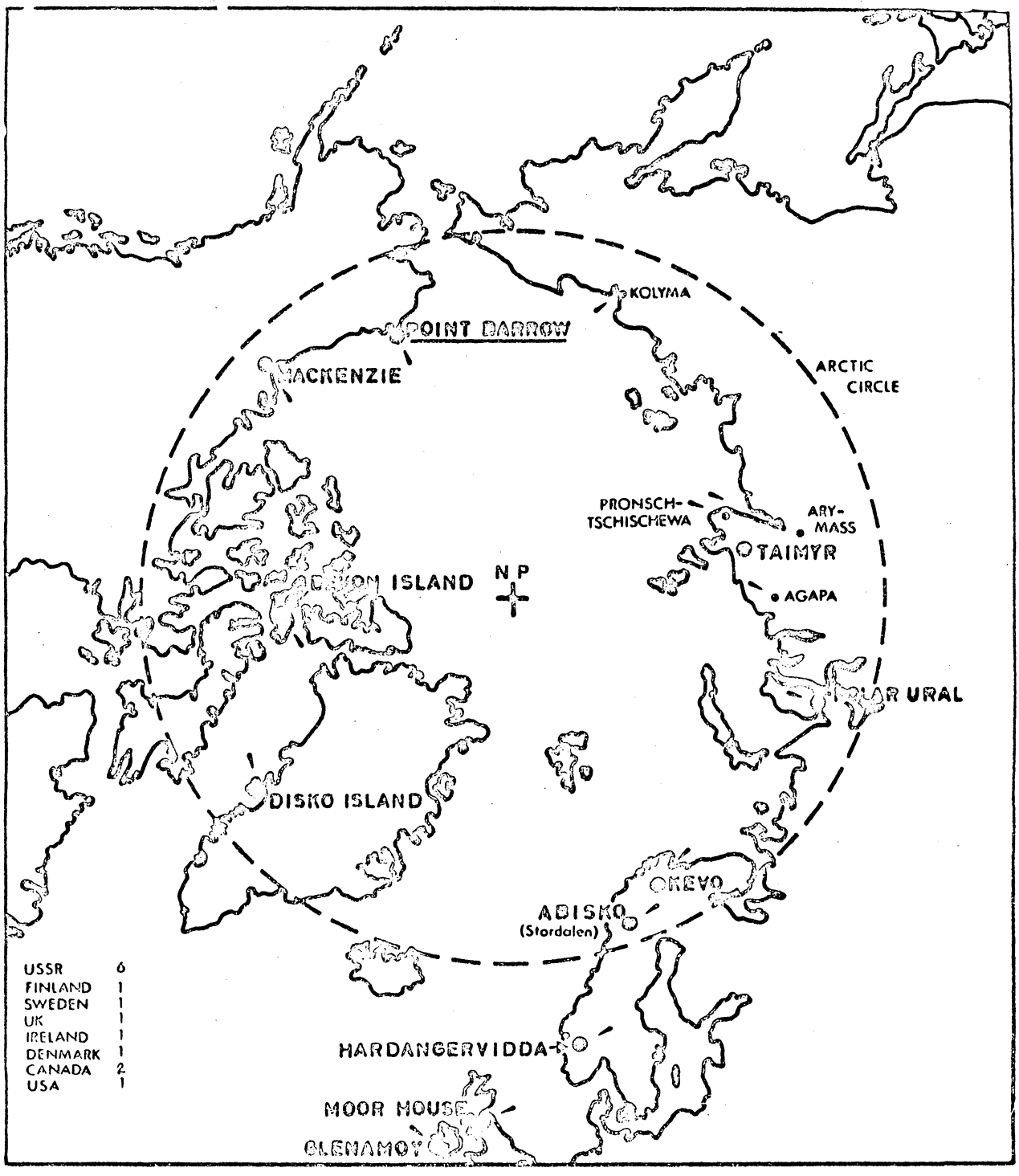


Figure 1. International Biological Programme Tundra Biome Site Map.

was in the soil and how the mycelium fluctuated through the season, with depth, and what the relationship was between the mycelium and the moisture gradient. This study forms the basis for this dissertation.

Concern was then directed toward methodology and sampling for belowground fungal biomass. The recognition of a plan of study and how this study would best fit into the developing schemes and philosophies of a totally integrated research effort, as were stated in the Foreward to this dissertation, were primary in choosing the direction of study. In any study of soil microflora several components must be considered.

First, soil profile horizons are variable in number with respect to any given soil system. The tundra soils of high latitude wet coastal plain tundra, which persists perhaps in spite of the influencing abiotic parameters of temperature and moisture, and unlike forest soils of the boreal and deciduous forests, often lack defined horizons. The litter horizon, because of the dominance of graminoid vegetation, was essentially composed of standing and fallen dead herbage. This zone in the area of the U.S. IBP Tundra Biome sites may be 10-20 cm deep. Depth assignment is very misleading as abrasive winter snows usually reduce any standing dead materials that Arctic Brown and Collared lemmings bypass during their foraging within the subnivian spaces beneath the snow and above the tundra's surface.

Second, the litter horizon in some habitats of Arctic soil may be entirely absent. If in a depression, a polygon trough or drainage system, litter will often be carried away with snow melt-water runoff

in the spring, mid June, before it can even begin to enter the soil peat system. When litter is produced on a polygon top, rim or otherwise projecting geomorphic land feature it may literally be blown or abraded away before it can enter the peat soil system. My observations of Barrow tundra over the four year period clearly substantiate this. Where litter settles and enters the system it does so over stratified and increasingly unrecognizable layers of the organic litter (L) horizon. By comminution it may eventually pass into the ill defined fermentive (F) horizon, then into a humic (H) horizon where it may accumulate for literally thousands of years. Peat soil is a product of these degredational processes of comminution, partial digestion and decomposition. Living carpets of heterogeneous communities of mixed moss species may act as a physical barrier to letting the litter enter the peat soils beneath. During successive years organic debris eventually becomes a part of the decomposing substrate in some habitats as the mosses, grasses, sedges and other vascular plants grow up through the litter. Not until litter, in its partially decomposed state, reaches the soil system was it considered in the study of belowground fungal activity and biomass. This process of litter entering the soil may take several years. Furthermore, limitations excluded the study of above ground litter.

Third, it is apparent from the literature that a wide variety of organisms exist in tundra soils (Holding et al., 1974). These include the faunal nematodes, enchytraeid worms, mites, mollusks, insects, and the floral bacteria, yeasts, actinomycetes, fungi and algae. The only soil organisms considered in this study were the filamentous

fungi, which belong to the Phycomycetes, Ascomycetes and Basidiomycetes. Special concern has been directed to the higher fungi, which are constituted in the latter two classes, the Ascomycetes and Basidiomycetes. Basidiomycetes are relatively abundant in their fruiting as well as their vegetative phases. This study concerns itself primarily with the vegetative plant body, the mycelium, and its presence in the highly organic peat substrates. The concern was to know why mycelium was there, how much was there, and the function of mycelium as a fraction of the decomposer population in the ecosystem.

OBJECTIVES

My objectives in this study were to determine as nearly as possible the roles fungi played in an Arctic tundra and cold dominated ecosystem. I was particularly interested in the standing crop of belowground fungal biomass and how it was related to the various habitats along moisture dominated gradients that make up the Barrow ecosystem.

These objectives were:

1. to develop or modify an already existing technique for measuring the belowground fungal biomass (standing crop) on a series of plots which represent the five major habitat types at Barrow, Alaska.
2. to obtain seasonal information on fungal biomass in the soil profile to the depth of thaw.
3. to determine seasonal fluctuation trends from June thaw to September freeze-up over a multiple year sequence.
4. to determine relative hyphal growth rates in situ along a moisture gradient transect.
5. to determine the species composition of higher fungi in each habitat.
6. to obtain by recording both unclamped and clamped hyphae some idea of the distribution of Basidiomycetes in the different habitats.
7. to relate soil temperature, soil moisture, soil bulk density, soil nitrogen and phosphorous to the flucuations in fungal biomass over the season in several

distinct habitats along the moisture gradient.

8. to determine, C N P values of soil, fungal hyphae and fruiting bodies.

LITERATURE REVIEW

For nearly a century the presence of fungi in soil has been known, contemplated and researched. Adametz (1886) first isolated soil fungi. Waksman (1916) reviewed the early literature on soil fungi and raised the question of whether or not soil was an environment for an indigenous mycoflora (Waksman, 1917). He later concluded that there was a distinct soil fungus flora, at least in grassland soils (Clark and Paul, 1970). Waksman's conclusions were also supported by Werkenthin (1916), Brown (1917), Brierly (1923), LeClerg and Smith (1928) and Jensen (1931), who were soil mycologists of that era working in a variety of habitat types. Species of soil fungi, which were recorded early, belonged to four genera: Mucor, Aspergillus, Penicillium and Fusarium. The presence of fungi in soil has sparked the inquisitiveness and imagination of scientists from many disciplines. Fungi in soil types of all major biomes have been investigated from all parts of the world ranging from the tip of South Africa to alpine and high Arctic tundras. Wilson and Stewart (1956) studied disturbed soils while Nicholls (1956) studied chalk soils in England. Soils of the rhizosphere were studied by Naim (1967a). Cultivated soil fungi were studied by Warcup (1951a, 1959), Naim (1967b), Miller, Giddens and Foster (1957), Joffe (1963) and Jackson (1965). Cultivated soils in temperate habitats have undergone concentrated fungal research because of the impetus of agronomic and agricultural influences. Even though early workers were primarily interested in soils that were used for food production, a shift in research effort toward

pure rather than applied aspects of soil has occurred. Workers in many fields, e.g. mycology, plant pathology, pedology, etc., have attempted to answer ecological questions concerning the role of soil fungi, and to what extent biotic and abiotic variables influence fungal activity. Major thrusts in the research of soil fungi have resulted in the investigation of the associations that fungi exhibit with particular substrates or vascular plant floras. Other studies have explored: species complex changes within specific soil or plant community types; the effects of soil depth on fungal biomass, species composition; and the initial establishment of species in specific environments.

Work that closely followed efforts of early workers consisted essentially of descriptive research. This research led to the completion of several floras on soil fungi. Inquiry into the species composition of fungi in soils still exists today. Early emphasis was placed on disturbed and cultivated soils, but the pendulum has since shifted and the emphasis is now strongly directed toward detailed considerations of undisturbed "virgin" soils as reviewed by Paine (1927).

Early studies of virgin soils stressed the enumeration of species. Little was done to explore the biomass or turnover rates of soil fungi. Major contributions to the study of virgin soil mycoflora have been made in all biomes. Dowding and Widden (1974), Flanagan and Scarborough (1973, 1974), Hagem (1910), Hanssen, Thingstad and Goksøyr (1974), Hanssen and Goksøyr (1974), Laursen and Miller (in press) Miller and Laursen (1974), Miller, Laursen and Murray (1972) and Widden, Newell and Parkinson (1972) have contributed a great deal to

studies of the fungi of Arctic Tundra. Mosca (1957, 1960) and Rall (1965) have carried out studies in the alpine zone. Minor biomes, e.g. bogs and heathland, and other major biomes that have also been mycologically investigated for species of soil fungi include the boreal forest, high sonoran deserts, deciduous forests, grasslands, deserts, the tropics, Antarctic soils, and marine environments.

Since 1948, research on soil fungi has metamorphosed into an effort to develop new methods. One of the outstanding examples of this is the Jones and Mollison (1948) agar film technique for direct observation of soil microflora and its many modifications. A variety of different experimental approaches have resulted, as well as voluminous literature from the use of these new methods in soil mycology. The many new methods are reviewed extensively by a number of authors; Burges (1950, 1965, 1967), Griffin 1972, Johnson and Curl (1972), Parkinson, Gray and Williams (1971), Pochon, Terdieux and d'Aquilar (1967), Waksman (1952), Warcup (1950, 1951a, 1951b, 1960, 1967), and Youssef and Mankarios (1968).

Quantitative soil mycology was attempted as early as 1918 by Conn. He showed the value of direct observation in evaluating numbers of soil microorganisms, but his quantitative attempts were thwarted due to the 'state of the art' with respect to methodology. Warcup (1963) has referred to two basic approaches for the study of soil microorganisms. One series of methods involved direct microscopic examination of the substrate. The other incorporated a variety of isolation techniques that used selective media.

Many culture media, as reviewed by Johnson and Curl (1972) and

Papavisas and Davey (1959), have been used. Isolation methods were used by most workers in studies of soil fungi because the techniques allowed for subsequent identification of the isolated organisms (Warcup, 1963). Most isolation techniques selected for the fast growing filamentous soil fungi. Therefore, most early workers reported abundant phycomycetes and imperfect fungi from soil. Reports over the years have routinely included species of Alternaria, Trichoderma, Cliocladium, Fusarium, Aspergillus, Penicillium, Mucor and Cladosporium among a number of imperfect fungi which were cultured consistently in all major soils of all major biomes. Ascomycetes were frequently isolated, but species found and reported depended strongly on the media used. Basidiomycetes were almost never isolated because of the way in which samples were prepared, and the inability of these fungi to compete with fast growing molds on culture media. It was not until the work of Warcup and Talbot (1962), using the chaff method of Warcup (1959), the wood-block method of Tamblyn and DaCosta (1958), and the soil method of Flentje (1956), that 42 basidiomycetes were isolated from soil. It was shown that these fungi were highly dependent on soil moisture and thus were very seasonal, and only 1/3 of them had clamp connections.

A wide range of methods including dilution plates, soil plates, hyphal isolation, and isolation from roots were employed. Isolations of fungi in pure culture from sclerotia and rhizomorphs from the soil were successful. The chaff, wood-block and soil methods mentioned above were specifically used to obtain fructifications of known basidiomycetes, but were not used in this study. Warcup (1959)

sterilized wheat chaff in tubes, inoculated the chaff and allowed it to become permeated with the mycelium. This 'starter' was then placed into earthenware pots on sand, covered with soil, peat, more sand or sphagnum and kept moist. Fructifications appeared 1 to 8 weeks after potting.

The wood-block method of Tamblyn and DaCosta (1958) resulted in fruiting of an entirely different flora from the same soil. It is interesting to note however, that members of the Polyporaceae were never isolated from soil by this or any other technique used by Warcup and Talbot (1962). The wood block technique consisted of first producing a lush growth of inoculum on fine chaff and perlite to which was added a block of sterile balsa or palm. Fructifications appeared 2 weeks to several months later. In the soil method used, an inoculum was produced on maize-meal-sand which was mixed with the soil, thoroughly watered and allowed to dry before the next watering. Fructification appeared on the clods of soil 1 to 6 weeks later. Species of basidiomycetes which were isolated using the chaff, wood-block and soil methods belonged to several genera of four orders. Found were: Serbacina, Oliveonia Donk em. Talbot, and Thanatephorus Donk in the Tulasnellales; Waitea, Corticium Fr., Cristella Pat., Sistotrema Fr., Athelia Pers. em. Donk, Physalacria Peck, and Leptoglossum Karst. in the Aphyllophorales; Omphalina, Marasmius Fr., Marasmiellus Murr., Leucocoprinus Pat., Agrocybe Fayod., and Coprinus Gray in the Agaricales; and Cyathus Haller ex Pers. and Sphaerobolus Tode ex Pers. belonging to the Nidulariales. Fructifications were often thin, delicate, resupinate, effused over the soil, or slightly

raised, and lightly pigmented. This was, however, a part of the fungus flora in soil that had never appeared using the older techniques described above. Rarely found were stipitate and pileate species broader than 1.5 cm.

Johnson and Curl (1972) reviewed uses of other selective media and methods that had been developed over the past two decades for isolating specific taxa of soil fungi. Selective media were first developed for isolating fungi belonging to the Acrasiales by Kitzke (1952), the Chytridiales by Willoughby (1956), the Saprolegniales by Harvey (1925) and the Pythiales by Dick and Newby (1961). More recently, methods of isolating Ascomycetes by Warcup (1951c) and Warcup and Baker (1963), Basidiomycetes by Goos (1960), Warcup (1959) and Warcup and Talbot (1962), and even specialized fungi such as nematode trappers by Duddington (1955), have been developed.

It is apparent from the literature reviewed that isolation techniques fall into three major categories: 1) dilution plate methods, 2) soil-plate methods and 3) the immersion techniques, with all of the respective modifications and ramifications.

The first and perhaps the more widely used media technique, those of dilution plating, lend themselves to measuring spore inoculum potential referred to as the number of propagules. The technique favors fungi that sporulate heavily in soil. Sterile forms of soil fungi and soil inhabiting basidiomycetes rarely appeared when this method was used. Both sterile and basidiomycetous fungi were uncommonly seen when dilution plate methods were used.

Modifications of the dilution plate technique included the

syringe methods of Rodriquez - Kabana (1967), and the dropper-plate method introduced by Schenck and Curl (1961). These methods have, as an advantage to standard dilution methods, a much shorter processing time. Being cheaper and less time consuming, large numbers of soil samples can be processed. The actual weight of soil used can also be calculated so the number of propagules can be ascribed to some unit volume of soil, thereby eliminating much of the error common to serial dilution and pipetting methods. A high degree of reproducibility is also achieved. In summary, the soil dilution plate method presents an inadequate picture of the fungi in soil because it was grossly selective even when the main objective was to produce floristic lists (Griffin, 1972).

The soil-plate method, the second isolation technique category, was first introduced by Waksman (1916) and was modified by Warcup (1951a). It incorporated the dispersal of small quantities of soil over an agar plate. The advantage of this method was in obtaining those fungi whose propagules were associated with the larger soil particles. It permited the isolation of humus embedded soil fungi or soil fungi that might be attached to mineral particles that might otherwise have been discarded in the residuum of the plate preparation. Fast growing fungi were still favored and floristic lists did not differ greatly from those obtained in the dilution plate techniques of Griffin (1972). A modification of the soil-plate method was introduced by Aberdeen in 1955. It was called the plate-quadrat method of soil plating. The advantage of Aberdeen's modification was in its design to yield a more accurate estimation of the ecological distribution of fungi in soil based on the presence or absence of a

species in a quadrat of a known size (Johnson and Curl, 1972). Sand dilution, another modification to the soil plate method, was introduced by Johnson and Manka (1961). This method modification was useful when soil having high fungal populations were assayed. Sand dilutions reduce the number of colonies without losing the advantage of demonstrating the ecological distribution of various species in the soil. But the Basidiomycetes, known to be in the soil, were still not accounted for by this technique or its modifications (Johnson and Manka, 1961).

The third category of isolation methods, the immersion techniques, involve the introduction of agar substrates into the soil. It is assumed that any resulting colonization of the agar substrate will be by those fungi whose hyphae were growing at the site of substrate introduction (Griffin, 1972). The introduction of artificial substrate was accomplished by using agar coated and uncoated microscope slides by Rossi and Riccardo (1927) and Cholodny (1930). In addition, glass tubes and microtubules with and without agar media substrate were inserted into soils by Chesters (1949). Chesters and Thornton (1956), Mueller and Durrell (1957) and Anderson and Huber (1965) also employed microtubules and improved on their use. The minute microtubules had the advantage of simulating capillaries in the soil. In the present study I have used this technique successfully in wet to mesic peat soils of Arctic coastal tundra. However, because of desiccation, this technique failed in the sandy-loam soils of a beech-aspen taiga forest in central Alaska (Moore, pers. comm.). The problem of medium selectivity for certain species of

soil fungi still exists. The capillary method does allow the investigator to obtain in situ data on growth and colonization rates of soil fungi.

Other immersion techniques commonly used for isolating soil fungi included Thornton's (1952) screened immersion plate, Wood and Wilcoxon's (1960) plastic disc, Anderson and Huber's (1965) profile plate, MacWithey's (1957) capillary tube and Luttrell's (1967) strip bait technique.

Thornton's (1952) screened immersion plate modification had the advantage of inserting media into the substrate rather than inserting substrate into the media. Modification of Chesters (1948) immersion tube technique allowed for easy removal of media containing the isolated fungi from the substrate and allowed for easy isolation of the invading fungi. The plastic disc technique of Wood and Wilcoxon (1960) had the advantage of strategic inoculation of agar by soil fungi through holes of a plastic plate. Inoculation was accomplished by pressing the petri plate bottom containing the agar and the plastic plate agar cover over a soil surface. The in place dish was covered, but easily removed two or more days later for isolation of the inoculum. The profile plate of Anderson and Huber (1965) allowed one to study the distribution and association of actively growing fungi over a much larger soil surface than was tested using the plastic disc of Wood and Wilcoxon (1960). A large piece of plexiglass with many 'well' holes at various distances were filled with agar, taped over and wrapped in aluminum foil to be autoclaved. In the field a thin sheetmetal rectangle was vertically

inserted into the soil profile for minimal disturbance of the soil substrate. All soil from one side of the plate was removed. The plate was then removed and replaced by the immersion plate after holes were punched in the tape that covered the agar wells. Plates were removed after 2 to 5 days and the inocula were isolated in the laboratory. MacWithey (1957) used capillary tubes that were made from disposable capillary pipettes filled with a malt agar medium. The advantage of his capillary was in being able to force the agar out of the capillary into a long slender agar tube that could be sectioned and used for plating the inoculum. This method was employed in the Arctic. The strip bait method of Luttrell (1967) consisted of a series of nutrient impregnated filter paper discs that were sealed between tape. The discs adjust to ambient substrates moisture levels and were easily and inexpensively produced. Fungi were isolated from the filter paper discs for studies relating to fungal succession in the soil.

Direct observation methods, in contrast to the many isolation techniques of dilution plating, soil plating and agar immersions, have also been used in soil fungi research. An early account of direct observations of soil fungi was revealed in the method of rose bengal soil staining used by Conn (1918). Kubiena (1938) observed soil directly under a low power microscope without staining. He also successfully isolated and cultured fungi directly from the soil by a manipulative semi-micro technique. In situ direct observations of soil have been successful by using observation box methods that had glass observation plates for microscopic canvasing of an otherwise

unexposed soil surface. Box observation methods were devised by Dean (1929), Linford (1942), Parkinson (1957) and Sewell (1959a). From the late 1920's to the early 1960's slides and burial techniques of this kind were commonly employed. Uncoated glass slides were used by Rossi and Riccardo (1927), Cholodny (1930) and later by Brown (1958), Sewell (1959b) and Starkey (1938). A clean microscope slide was pressed against a soil surface and soil particles containing fungi would stick to the slide. These slides with adhered soil were easily examined for fungi. The slide, unlike the impression and immediate removal technique of Brown (1958), was left in place to allow in situ incubation. Slides coated with malt agar were used by Wright (1945). Gabe (1961) employed what he called a pedoscope that used no media to examine soil fungi. Lehner, Nowak and Seihold (1958) used a vital stain on their agar slides, a 1:750 solution of acridine orange, to observe fungi with fluorescence microscopy. The technique of Lehner et al. (1958) was adapted from Strugger (1948) with some modification. Waid and Woodman (1957) went even further and modified the buried slide technique to incorporate nylon gauze. Gams (1959) used a nylon strip. Johnson and Curl (1972) and Warcup (1950, 1960, 1963, 1967) have reviewed in detail still other direct observational techniques.

Another direct observation method of examining soil fungi was the soil block embedding and sectioning technique used by several investigators. The soil embedding technique had the advantage of allowing the study of the physical relationships of one mycelium to another mycelium and to the nonliving components within the soil

system. The technique utilized thin sections of soil cut from prepared soil blocks with a microtome. This made the technique costly in terms of time spent in preparation of soil for examination. Kubiena (1938) and Minderman (1956) used a gelatin embedding technique that allowed sections as thin as 7.5 µm to be cut and easily stained. Alexander and Jackson (1955), Hepple and Burges (1956) and Nicholas, Parkinson and Burges (1965) all used a polyester resin for embedding soil samples. Thin sections, ca. 50 µm, were cut, polished and mounted. One can use these for standing crop fungal biomass determinations without disturbing the in situ relationship of the fungi to the soil. Certainly, the greatest disadvantage to using these embedding techniques was in the tremendous investment of time, equipment, and materials, and the necessity of a well equipped laboratory to do the work. Use of strong acids, rock cutting and polishing equipment and turn-around time for data retrieval would discourage the use of soil sectioning techniques in an Arctic system where the season is short and where many samples needed immediate processing.

In quest for better direct observation methods of sampling for soil fungi from a variety of ecosystems the agar film technique was developed by Jones and Mollison (1948). Agar film techniques allowed for quick and easy preparation of a soil sample for direct observation of fungal mycelia. This technique opened up a whole new and refreshing thrust in the study of soil fungi. However, the evolution and use of agar film techniques were initially slow, but several modifications have since been developed. There was a lag from 1948 to

about 1957 when Hering and Knowles used the technique. They studied disturbed non virgin soils of England's woodlands and grasslands. The work of Gunsalus and Stanier in 1960 stimulated interest in the study of mycelial lengths and fungal biomass in soils, a departure from the much more traditional species list making. Burges and Nicholas (1961), Jagnow (1961), and Nicholas and Russell (1961) carried out studies using the direct counting techniques and expressed their results in what has since become the standard mode of expressing fungi in soil quantitatively as meters of mycelium per gram dry weight of soil (m/gdws). Many studies of this kind were stimulated by the International Biological Programme in various biome studies. Investigations have since been carried out in pasturelands, grasslands, deciduous forests, coniferous forests and tundra.

At first it was difficult to know if the m/gdws values obtained were realistic because comparative values for soil fungi lengths in other biomes did not exist. A number of studies (Table 1) have now been completed, especially in the last 3 years. The work of Jones and Mollison (1948) was used in most of these studies as well as in this work, but not without modification (Laursen and Miller, in press). The principle advantage of the direct count agar film technique was in the ability to measure the standing crop biomass of most soil fungi quickly and efficiently. The International Biological Programme adopted the quantitative expression, meters mycelium per gram dry weight of soil (m/gdws), in order to make inter and intrabiome comparisons.

The data compiled in Table 1 represents major contributions from

four biomes, the Arctic Tundra Biome of the U.S., Canada, Sweden and Norway, the Coniferous Forest Biome of Canada, the Deciduous Forest Biome of Canada, England and the Netherlands, and the Grassland Biome of the U.S., England, New Zealand and Canada, over a 26 year period. Fungi have also been found in peat and mor soils of England, and even in snow from Sweden (Hanssen and Goksøyr, pers. comm.). The Taiga Biome in the U.S. is also presently under study.

The levels of fungal biomass between Biomes varies a great deal from site to site, but generally, tundra soils with mycelium lengths ranging from 453 to 5500 m/gdws have the greatest soil fungal biomass. Tundra soils are followed by deciduous forest soils with a standing crop fungal biomass of 511 to 2640 m/gdws. Grassland soils followed with a range in belowground fungal biomass of 113 to 2327 g/gdws. Coniferous forest podzols showed 1469 m/gdws for the lowest of all Biomes represented in Table 1. The greatest fungal biomass resided within the litter zones of these Biomes where hyphal lengths ranged from 1546 to 7000 m/gdws.

Studies in these biomes were essentially short term 1 to 2 year studies. The results were reliable estimates of the fungal biomass. Studies on the occurrence of soil fungi that were extended over a 3 to 4 year period, in an attempt to ascertain seasonal progression, were not found in the literature. At the initiation of this work, there was no definitive work of this type on soil fungi from Arctic tundra. The need for a comprehensive and quantitative study of belowground standing crop fungal biomass, and particularly in the Tundra Biome, became apparent. This was the impetus that led to the present study.

TABLE 1

QUANTITATIVE MYCELIAL MEASUREMENTS

Investigator(s)	Location/Soil type	Mycelial length by soil vol. or depth
Burges & Nicholas, 1961	England Pine-humus podzol	1.04-5.67 m/cc
Clark & Paul, 1970	U.S.A. grasslands	138 g/m^2/30 cm
Doxtader, 1969	U.S.A. grasslands,	446 m/g/10 cm
	Ascalion sandy loam	379-609 m/g/10 cm
Flanagan & Scarborough, 1973 & 1974	Barrow, Alaska litter	4000-7000 m/g
Gunsalus & Stranier[1], 1960	grassland	7-62 g/m^2 wet wt.
Harris, 1970	England grasslands, grazed-ungrazed	2327 m/g/10 cm
Hanssen & Goksøyr, pers. comm.	Hardang., Norway	
	wet meadow	182 m/g/10 cm
	dry meadow	113 m/g/10 cm
	lichen-heath	50 m/g/10 cm
	birch-forest	204-3000 m/g/10 cm
	snow	69 m/g/10 cm
	Stordalen, Sweden	
	hummock	5200-5900 m/g/10 cm
	depression	5700-6000 m/g/10 cm
Hayes, 1972	Stordalen and Njulla, Sweden	2400 m/g/10 cm
	hummock	6514 m/g/10 cm
	depressions	6526 m/g/10 cm
Hering & Knowles, 1957	England woodland	550-1070 m/g
Jackson, 1965	New Zealand pasture	65-160 m/g
Jagnow, 1961	Meadow humus	650 m/g
Jensen, 1962-3[1]	Australian grasslands	17-330 g/m^2 wet wt.
Jones & Mollison, 1948	England grasslands	25-792 m/g
Latter & Cragg, 1967	Canada aspen forest	
	litter zone	1412 m/g
	fermentive zone	1680 m/g

[1] g/m^2 dry wt. not known, but would be 10-15 % of the wet wt.

TABLE 1 Continued

Investigator(s)	Location/Soil type	Mycelial length by soil vol. or depth
Latter, Cragg and Heal, 1967	England juncus mor	100-2000 m/g
	grassland	450-1600 m/g
Laursen & Miller, in press	Barrow, Ak. soil	60-2525 m/g/7 cm
Nagel de Boois, 1970	Netherlands forest	
	oak-beech litter	1703-2149 m/g
	fermentive	2000-2280 m/g
	humus	5253-8473 m/g
Negal de Boois & Jansen, 1966	oak forest	
	mull and mor	98-924 m/g
	organic soil	1778-6182 m/g
Nicholas, 1962	podzol	136 m/cm^3
Miller, Laursen and Calhoun 1972	Barrow, Ak. tundra	this dissertation 553-5500 m/g
Miller & Laursen, 1974	Barrow, Ak. tundra	128-1593 m/g/7 cm
Parkinson, pers. comm.	Saskatchewan grassland	51.9 g/m^2/10 cm
Parkinson, 1970	woodland soil	7000 m/g
Russell, 1961	England	165 g/m^2
Stockli, 1956	peat	700-9000 m/g
	woodland	2640 m/g
	other	100-2000 m/g
Visser, 1971	Sask., Canada	
	leaves	13-418 m/g
	aspen litter	589-4773 m/g
	fermentive$_1$	3062-7930 m/g
	fermentive$_2$	3788-7215 m/g
	humus	6249-5996 m/g
Visser & Parkinson, pers. comm.	aspen litter	100-4500 m/g
Widden et al., 1972	Devon Island, Canada	
	mesic meadow	1615 m/g
	meadow	3417 m/g
	raised beach	306 m/g
	beach ridge	143 m/g

TABLE 1 Continued

Investigator(s)	Location/Soil type	Mycelial length by soil vol. or depth
Widden & Parkinson, 1974	Canada pine forest	
	lodgepole humus	2699 m/g
	A_1	1540 m/g
	A_2	351 m/g
	B_1	140 m/g
Widden & Parkinson, 1975	Canada forest, burned	
	Lodgepole humus	4477 m/g
	A_1	2159 m/g
	A_2	286 m/g
	B_1	97 m/g

BARROW SITE DESCRIPTION

In North America, the Alaskan high latitudes reveal a vast and northerly dipping coastal plateau marked with an expanse of oligotrophic lakes, ponds and aquatic habitats, which cover 50 % to 85 % of the land's surface area (Fig. 2). The remaining land surface is covered with a select acid peat soil called tundra. Concern here is for tundra which encompasses the vast treeless and grass-sedge plain north of the 10 C July isotherm. This grass-sedge plain is sectioned into Arctic low and middle tundra.

The Alaskan North Slope is densely clothed, unlike the Antarctic, with poikilohydric (bacteria, algae, fungi and lichens) and homiohydric plants, which resist dehydration under normal climatic changes for that area (Walter, 1973). This group of organisims was placed by Walter into his 9th vegetational zone, the 'Arctic tundra zone'. The Arctic flora, its distribution and the adaptations of Arctic plants to the environment, have been intensively studied. North American Arctic flora have been extensively studied by several botanists a few of whom were; Britton (1966), Eyre (1968), Hultén (1941-50), Polunin (1960), Porsild (1957), Savile (1972), Wiggins (1951) and Wiggins and Thomas (1962). Floras from a variety of locals within the Arctic archipeligo have been authored by such men as Anderson (1943-1952), Bentham (1865), Fernald (1933), Hultén (1941-50), Polunin (1960), Porsild (1957), Raup (1931, 1943), Torrey and Gray (1838-1840) and Wiggins and Thomas (1962). However, the U.S. Arctic tundra, which extends from west to east across some 900 km and 180 km north to south, has been worked primarily by Hultén (1968) and Wiggins and Thomas (1962). Tundra

Figure 2. An expanse of North Slope tundra 90 miles SE of Barrow, Alaska showing several dominant surface features: ponds; lakes; polygonal ground; and streams.

Figure 3. Mead River, the largest trunk of the tundra drainage system, 60 miles south of Barrow, Alaska.

Figure 2. Arctic Tundra Lakes of the Coastal Plains Province, Alaska.

Figure 3. Mead River at the Naval Arctic Research Laboratory Campsite, Alaska.

relief is subdued, with elevations along the coast at or near sea level. Relief increases ever so slightly southwardly for 200 km where tundra contacts the foot-hills province of the Brooks mountain range. Permafrost, first discovered by Middendorf (1864) in USSR tundra, underlies the entire US north slope region 20 to 100 cm below the grounds surface to varying depths. Permafrost extends downward 300 m in many areas and to 405 m near Barrow, Alaska. Exceptions to the presence and depth of permafrost exist under deep lakes, e.g. Peter's Lake, and the major river channels of Mead R. (Fig. 3) and the Colville R. (Fig. 4) where no permafrost is found in the upper soil layers at all (Brown and West, 1970). Because of the hydrologic freeze-thaw cycle, activity resulting in the formation of polygonal surfaces (Fig. 5) is common in the study area. Polygons come in a variety of shapes and sizes. Drainage from tundra surfaces is poor and, for the most part, is lateral due to the imprevious permafrost layer. Soils are often water saturated for most of the season and the permafrost acts as an impenetrable barrier for water percolation. Small streams meander and many become incised. Others develop vast flood plains (Fig. 4) where they often become heavily braided before emptying into the Arctic Ocean. Streams wander as do the characteristic footprint-like lakes (Fig. 2), which have northwest-southeast longitudinal orientations. As lakes and ponds migrate they flow into one another. Lakes often become completely drained after which the old lake bottoms undergo morphologic changes that result in typical patterned ground (Fig. 5). Summertime climate is coolest along the coast, which acts as a temporary haven for the Eskimo (Uniut) people

Figure 4. The heavily braided Colville River flood plane and delta 40 miles west of Prudhoe Bay where the North Slope's largest river empties into the Arctic Ocean.

Figure 5. Polygonally patterned ground comprised of low and recessed center polygons still inundated from melting snows as seen in late Spring.

Figure 4. The Colville River Delta and Flood Plane on the North Slope Coast, Alaska.

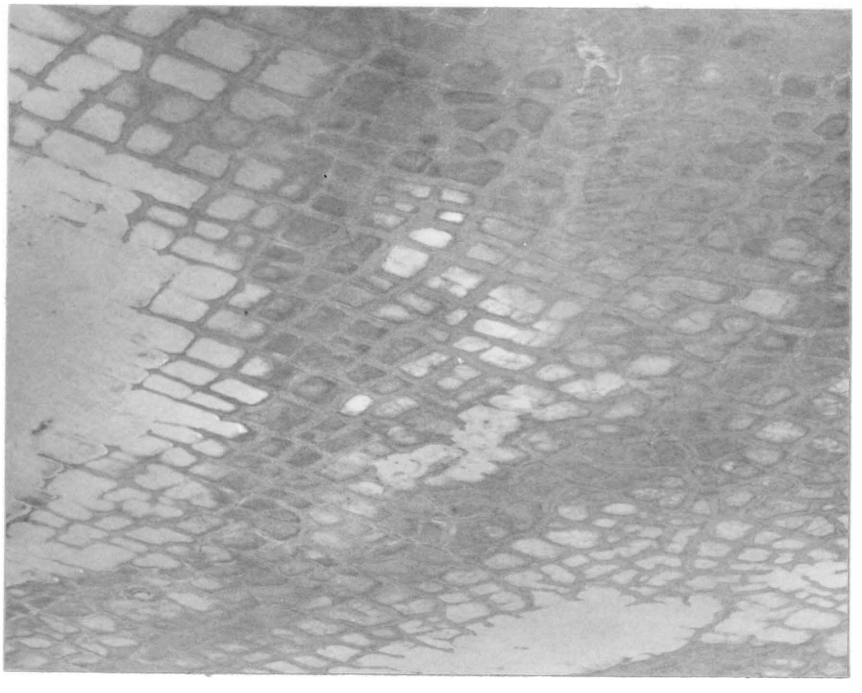


Figure 5. Patterned Ground of Polygonal Geomorphology near Barrow, Alaska.

and the migrating caribou in their attempts to escape Arctic mosquitos and other insects. Weather conditions vary considerably on the Arctic coastal plain. Umiat (Fig. 6), 240 km south of Barrow, is much colder in the winter and much warmer in the summer than temperatures recorded at Barrow. Interior Fairbanks, 700 km south of Barrow and south of the Arctic Circle, may have winter lows of -24 C. Coastal Anchorage (Fig. 6), while under the influence of an oceanic climate, has mild winters. Both have climates that are vastly different from coastal Barrow.

In the spring of 1970 several sites for scientific investigation were delimited along the northern shore of the coastal plateau just south of Pt. Barrow (Fig. 7). The sites were selected by the U.S. International Biological Program for its Tundra Biome intensive ecosystem study area (Fig. 7). These sites (1 to 12) were located on coastal low wet meadow tundra 71° 17' N Latitude, 156° 40' W Longitude circa 2 km east of Barrow Village and 2 km south of the Naval Arctic Research Laboratory (Fig. 8). The rectangular area in Fig. 9 encompases the intensive study area that was approximately 1400 m wide E to W and 1400 m long N to S. Sites 1 to 12 were defined by Footprint Creek on the north and down the middle. Gas Well Road bordered on the east, Footprint Lake on the south and the old raised beach ridge on the west. These sites, and principally Sites 2, 3 and 4 (Fig. 9), were the areas most intensively sampled during the five year IBP study, 1970-1975. These three sites represented an area approximately 700 meters wide E to W and 1400 meters long N to S.

Figure 6. Sites and locations in the state of Alaska where fungi have been collected and where soil samples have been taken and examined for soil fungi.

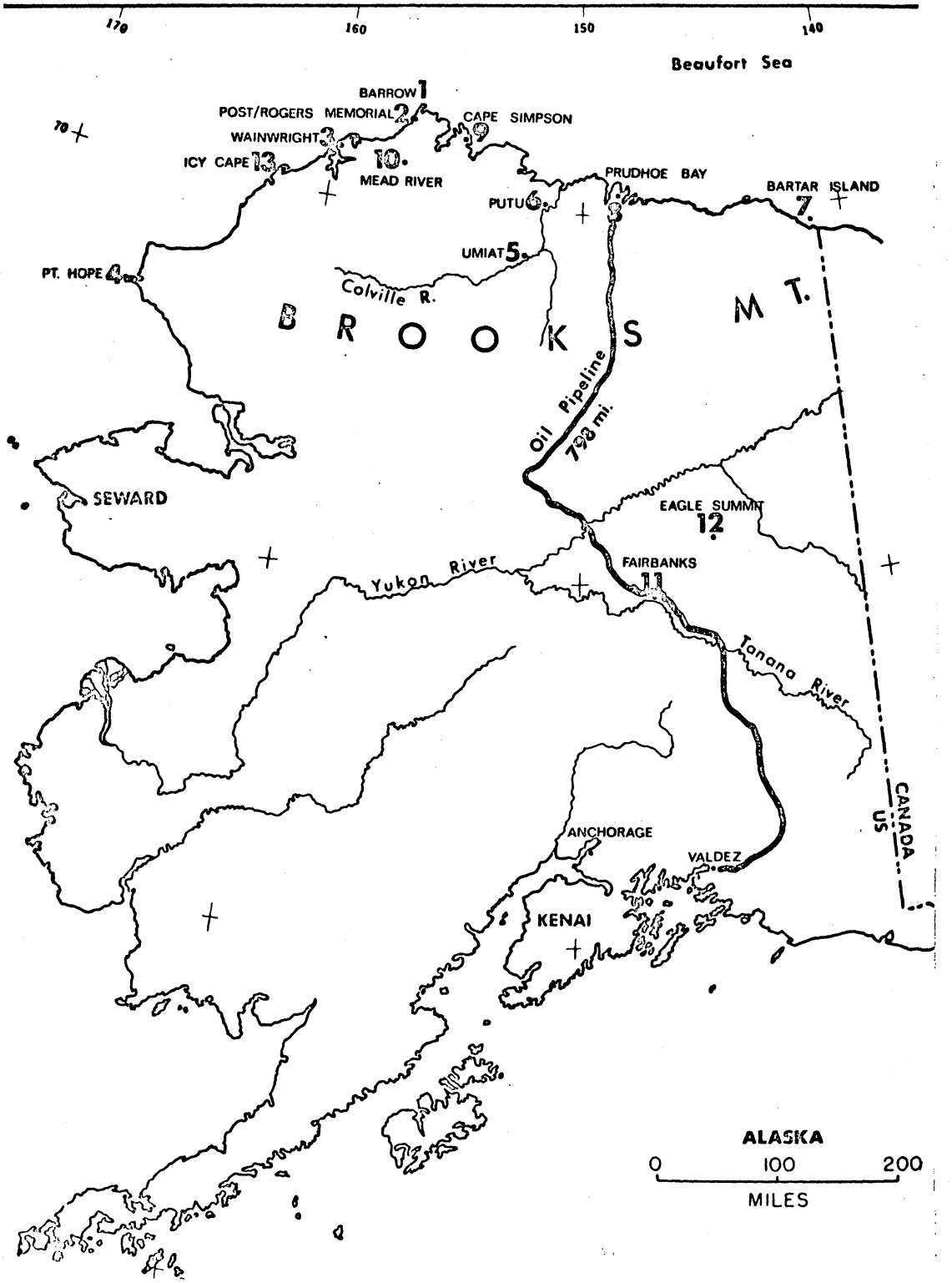


Figure 6. Location and State Map of Sites Involved in TB U.S. IBP Field Observations.

Figure 7. The northern most U.S. land mass on the North American continent that projects into the Arctic Ocean, Pt. Barrow, Alaska. The Eskimo (Uniut) Village, Naval Arctic Research Lab and the IBP Arctic tundra intensive study Sites are located 7 to 9 miles south of the Pt.

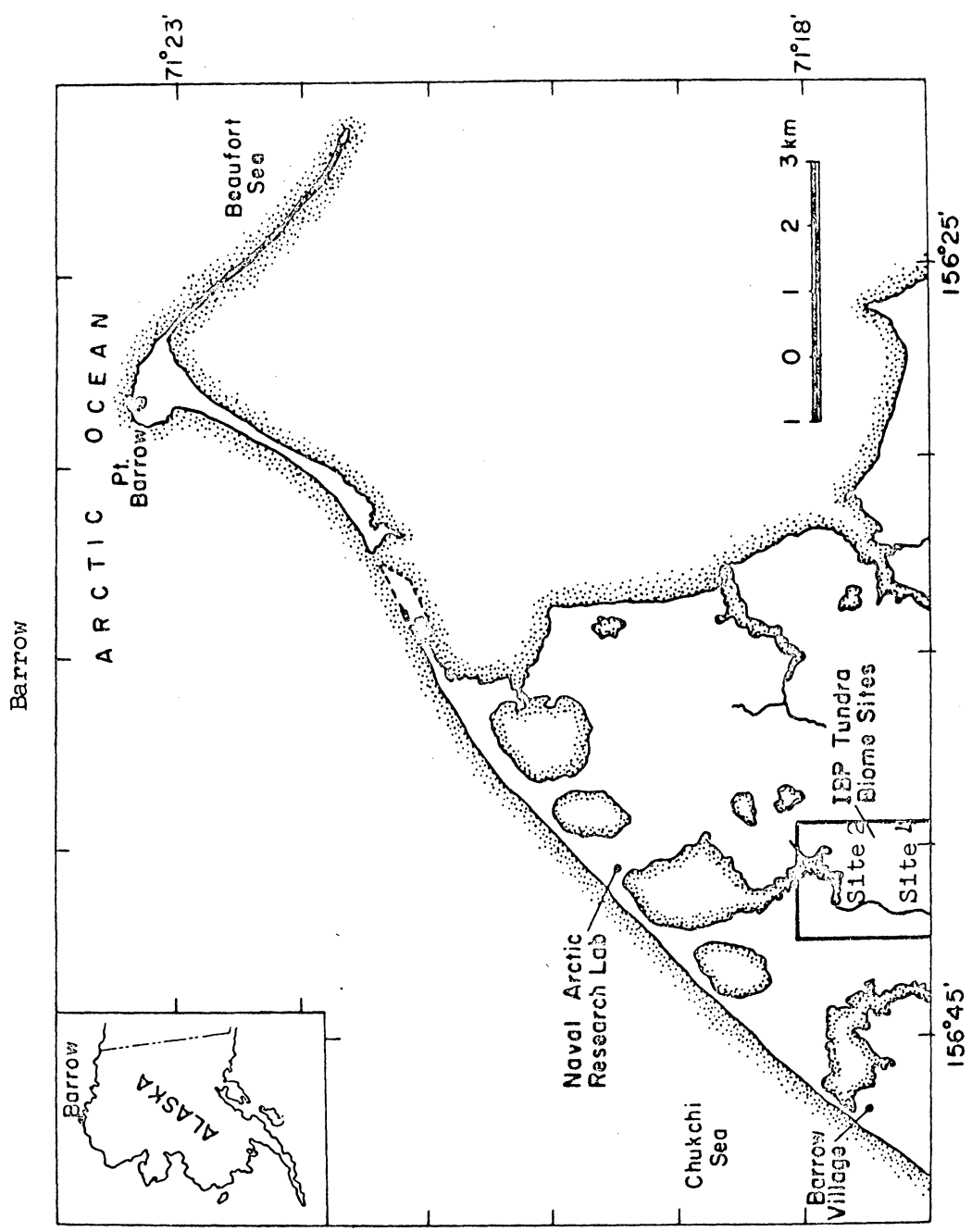


Figure 7. Location map of Barrow IBP Tundra Biome Sites.

Figure 8. USA CRREL Aerial Photo of the U.S. International Biological Programme Sites and the Naval Arctic Research Laboratory as seen in early Spring with the ice pack still intack.

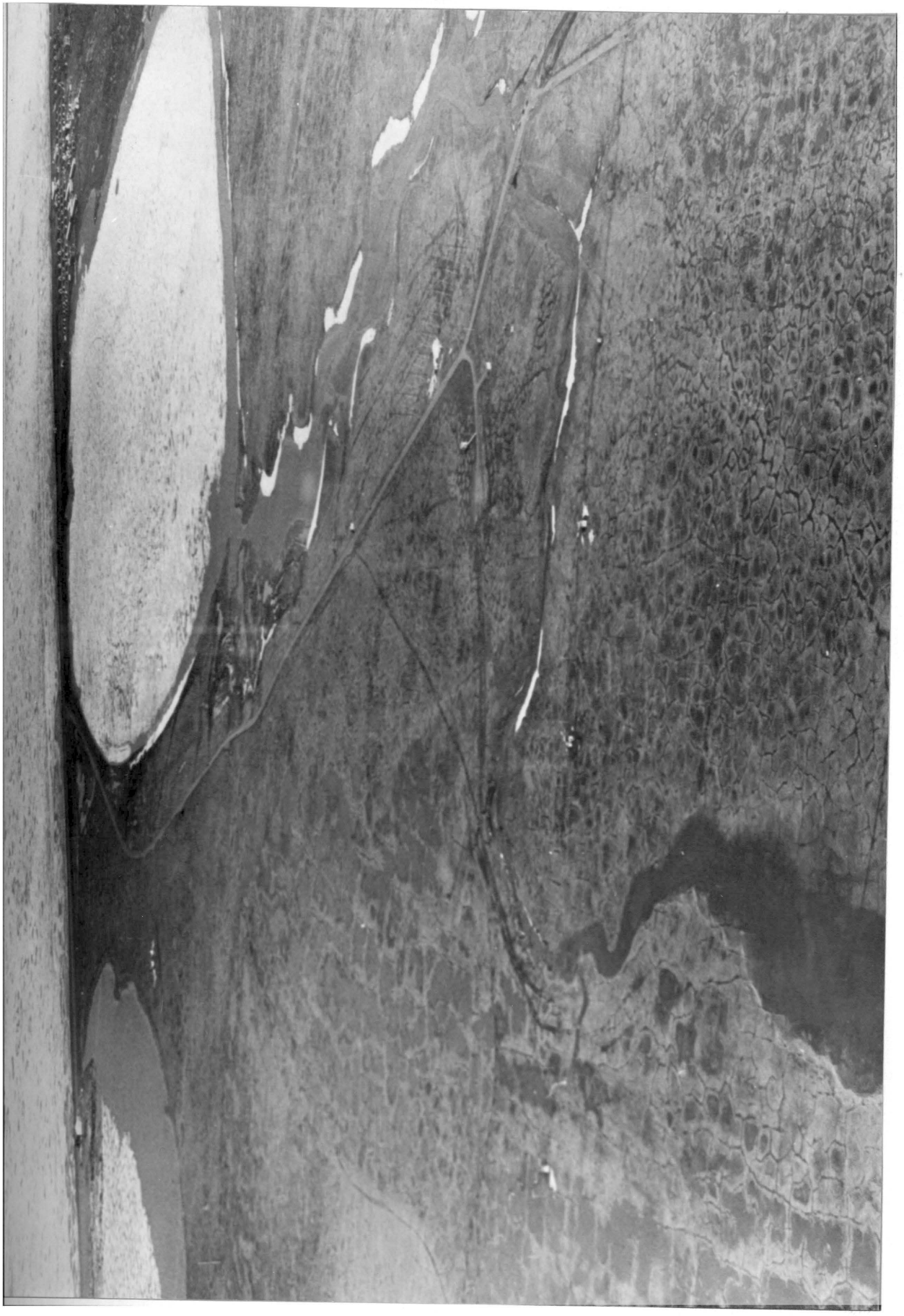


Figure 9. The U.S. IBP intensive study Sites 1 to 5 and 7, and logistic buildings 1.5 miles south of the Naval Arctic Research Laboratory, Barrow, Alaska.

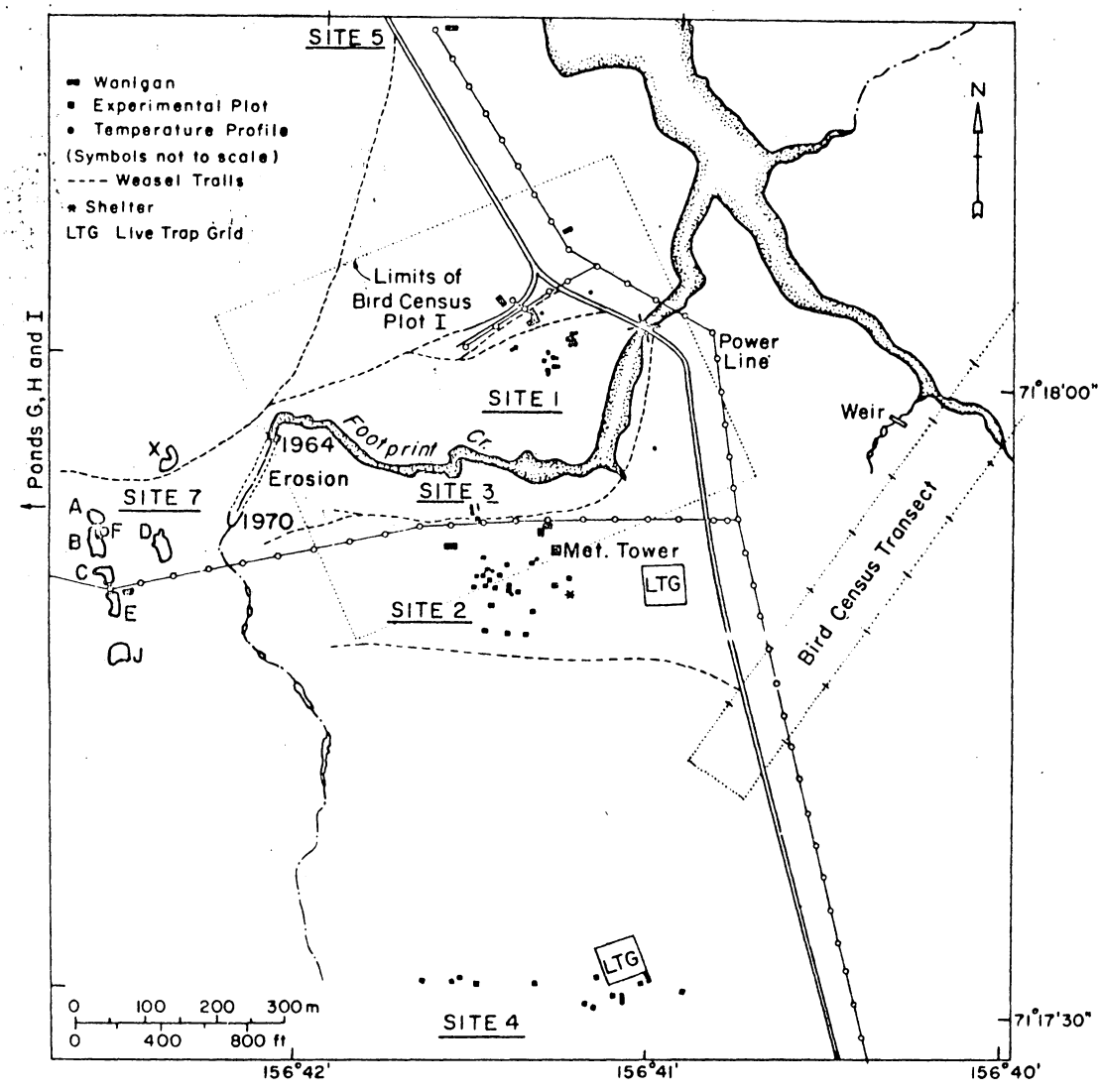


Figure 9. Schematic Map of Intensive Study Sites, Barrow, Alaska.

Thirty-three plots, characterized in Table 11, and located on 5 of the 12 sites, were intensively sampled for fruiting bodies of higher fungi (Ascomycetes and Basidiomycetes) and for belowground fungal mycelium biomass.

Much of the ground's surface over these sites was polygonally patterned (Figs. 5 and 8). An extensive trough system was formed. Sites 2 and 4 sloped gently to the west from Gas Well Road to Footprint Creek (Voth Slough), a vertical drop of about .78 m in a distance of 700 m (Figs. 8 and 9). From the drainage creek the land rose westwardly in a series of four uplifted beach benches that culminated in an old beach ridge 3.82 m vertical rise above the slough (Fig. 10). A schematic cross section of the E to W macro moisture gradient (Fig. 11) shows these undulating relationships. The transect paralleled a moisture gradient that was easily defined by its physiographic land surface features, peat thickness, and its characteristic plant communities.

Climatically there were many factors that greatly influenced the three moisture gradients, and indeed all of the IBP sites. Such climatic parameters included temperature, precipitation and relative humidity as they were related to winds and sea ice.

Temperatures were often used at one time to characterize tundra environments and especially Arctic tundra. Tundra near Barrow, Alaska is somewhat atypical for most other Arctic tundras. The Arctic Ocean surrounds the Barrow peninsula on the north, east and west. The tundra is almost flat with minor undulations. It extends some 300 km to the south through two upraised plateau provinces, the Arctic Coastal

Figure 10. An upstream view of Footprint Creek as seen in mid season showing headward errosion that has resulted from snow melt-water runoff, a natural perturbation.

Figure 12. A high topped polygon surface that is exposed during the winter and heavily abraded by wind blown snow crystals. As a result of the snow abrasion no plants have taken hold on the uplifted peat surface.

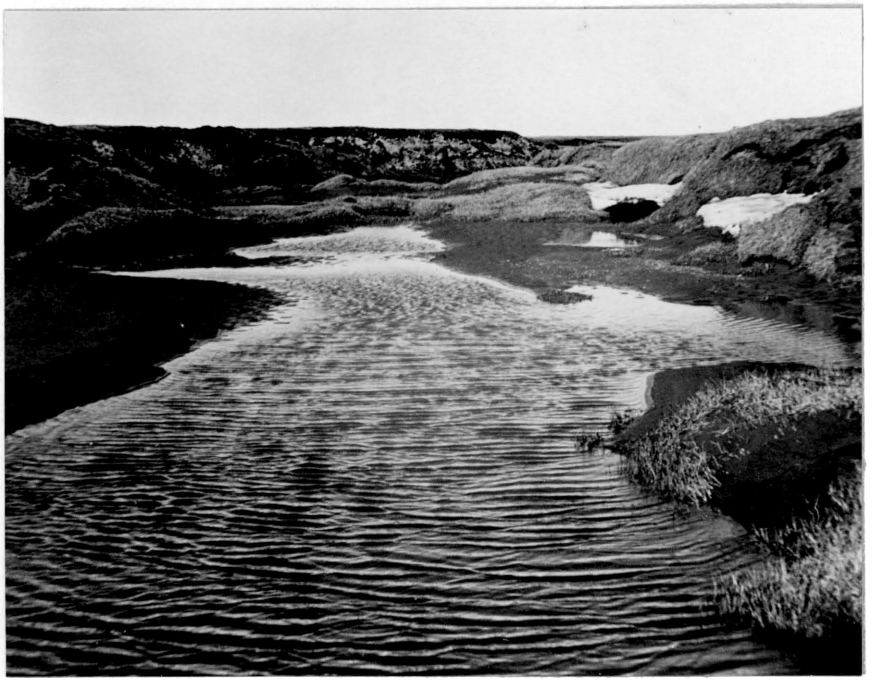


Figure 10. Voth Slough (Footprint Creek), Western Boundary of Intensive IBP Sites, Barrow, Alaska.

Figure 12. Wind and Snow Errosion of a High Centered Polygon, Barrow, Alaska.

Figure 11. A cross sectional profile of the 1400 meter moisture gradient transect as it is related to mean sea level and plot location.

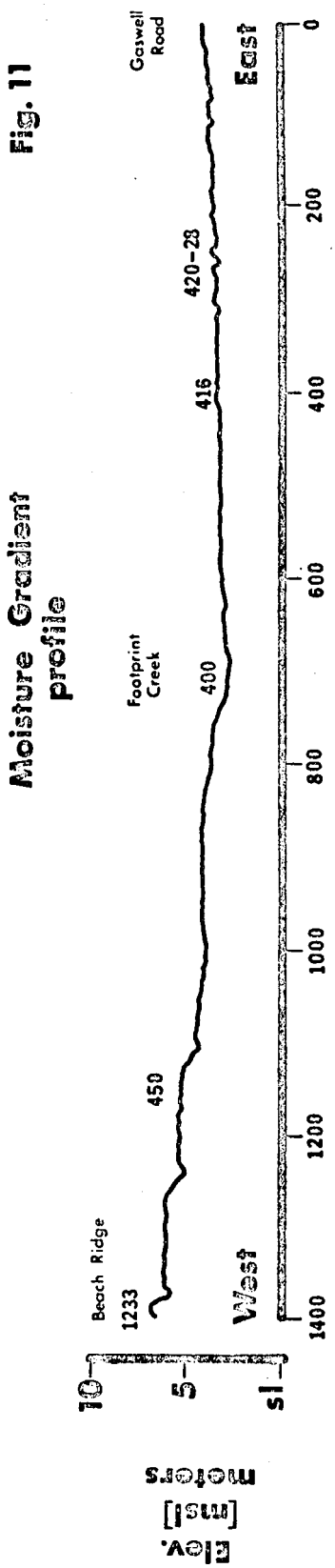


Figure 11. Macro-moisture Gradient Transect Profile, Barrow, Alaska.

Plain Province and the Foothills Province. Temperatures here have been found to be greatly influenced by the prevailing northeast winds. There are no natural wind barriers on the tundra near Barrow to interrupt the prevailing NE winds. Thus, convection or radiation currents are quickly dispelled. There is never a pocketing of air down slopes into valleys or canyons as they simply do not exist at the macrorelief levels. Consequently, temperature inversions in the lower atmosphere are not as detectable on the North Slope, if at all, as they are in the interior and Fairbanks. Winter ice fogs are examples of these inversions in Fairbanks.

Temperatures in Barrow remain below the freezing point through most of the year. Daily maxima reach above -1.1 C, on about 109 days a year. Daily minima drop below freezing approximately 324 days a year and freezing temperatures have been observed during all months. February is generally the coldest month with a normal mean of -27.0 C. The lowest temperature ever recorded, -28.9 C, was recorded in February of 1924. In April, temperatures are steadily increasing. By mid May winter fades and summer begins. The months of the field season, June, July, August and September for 1971-1974, had cool means of .9, 4.1, -2.2 and -.9 C respectively. July was the warmest month, but on occasion summer temperatures of 21, 25.6, 24.4 and 16.7 C respectively were recorded during the four summer months.

As early as mid June the sea ice will move out and away from the beaches to expose the Arctic Ocean. Cool temperatures and onshore breezes typically bring in fog over the tundra after the ice leaves. In a predictable pattern the occurrence of clouds, precipitation and

heavy fogs, build to a maximum as the number of daily sunshine hours increases. At 12:50 p.m. on December 18, the sun dips below the horizon and is not seen again until 11:51 a.m. on January 24. By approximately 9 minutes per day the amount of daily sunshine increases until 1:06 a.m. on May 10, when the number of daylight hours has increased to 24 hrs per day. On August 2, the sun finally sets for 1 hr and 25 min.

Climatic records kept since 1934 show low precipitation levels with a 40 year mean of 11.5 cm/yr. The range, from the low in 1935 to the high of 1963, was 4.09 to 24.82 cm of rain, fog, and snow per year. Mean snow fall was 27.2 cm for the same period with a 3 cm low in 1935 and a 60.8 cm high in 1964. Slightly over half of this precipitation, 59 %, is received during the 109 day summer season. Approximately $\frac{1}{4}$ of the total rolls in as fog during the month of August. Most of the annual precipitation, not all of which is rain, occurs then in a short time during the fall of the year.

Mean wind speeds for the period from 1935 to the present were 11.9 m.p.h. Relative humidity, even with a persistant wind, was still high and fluctuated between 78 and 96 %. Lower humidities were detected around 2 p.m. each day and higher values were detected during the early morning and early evening hours.

The ocean is the major water source of precipitation and until the ice leaves precipitation of any kind is minimal.

Geographically, the IBP moisture gradient transect (Fig. 11) extended from patterned or polygonal ground having both high centered and low recessed centered polygons of varying heights to and through a series of low profile polygons. It passed through mesic meadow and wet

meadow tundra, through Voth Slough, over a series of four successionally elevated beach benches, and terminated on an elevated ridge. The first bench was mesic meadow tundra with many small ponds and low centered polygons. The second and third benches were comprised of increasingly higher raised center polygons. The transect terminated on the fourth bench composed of very high rounded mounds that were frequently visited by the snowy owl, Nyctea nyctea.

Morphogeologically the area of the transect is young and presently in a state of dramatic change. Prevailing winds come from the NE and direct the movements of whole pond and lake systems in a unidirectional erosion pattern. These ponds and lakes are characteristically elongated with the major axes aligned 10 to 15° west of true north. Lewellen (1972) has shown from aerial photographs that differential erosion of only the north and south ends of the ponds resulted in their migration at a rate of 1 m per year. These moving aquatic systems act as "leveling" forces on the topography. But once the "moving" system is drained away by anastomosing with another, multiple geologic forces, such as abrading winter winds (Fig. 12), ice wedge formation (Fig. 13) and frost heaving and boiling (Fig. 14), constantly churn up and expose tundra surfaces. Where peat soils have accumulated, relative ages at depth have been estimated to range from approximately 2,000 to 8,000 years. Accumulated peat that becomes exposed is soon after mechanically decomposed (Fig. 15) by ice crystal formation (Fig. 16) and freeze-thaw cycles.

According to Flint and Gersper (1974) Arctic tundra soils on the North Slope, and particularly those in the vicinity of Barrow, are

Figure 13. A cross section of tundra near Footprint Creek as seen in the area immediately below a polygon trough and showing the persistant ice wedge, above which is the active layer and below which is permafrost.

Figure 14. Mud domes formed during the hydrologic freeze thaw cycle and resulting from lense shaped ice dome buildup several centimeters below the ground surface near Barrow, Alaska.

Figure 13. Ice Wedge in a Shallow Polygon Trough Site 2, Barrow, Alaska.

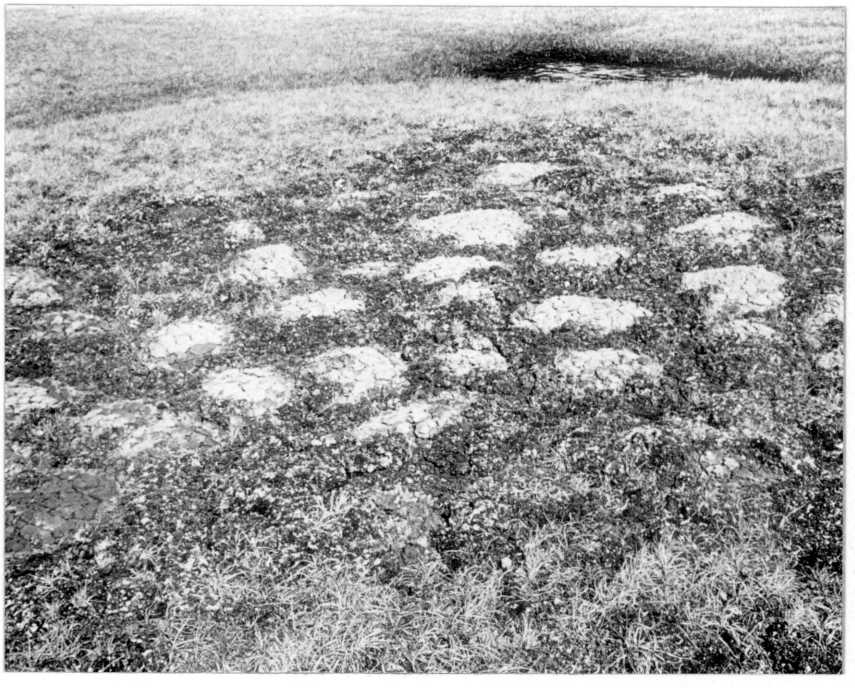


Figure 14. Mud domes produced by Frost Heaving of Lenticular Ice, Barrow, Alaska.

Figure 15. The resulting appearance of a peat mat after long periods of exposure to the elements and to the freeze thaw cycle, which results in mechnaical degradation and eventual recolonization by invading plant species most of which are grasses.

Figure 16. Massive subsurface ice crystal formations in permafrost soils several feet below the surface of the tundra in the vicinity of the raised beach ridge on IBP Site 12.

Figure 15. Mechanical decomposition of Exposed Peat Scarp, Barrow, Alaska.

Figure 16. Ice Crystal Formation at 10' depth in Permafrost Zone, Barrow, Alaska.

conveniently placed into two soil orders as defined by the U.S. Soil Classification System. The classes are inceptisols, or immature soils having weakly expressed profile characteristics and retaining close resemblances to parent materials; and histisols, which are organic soils. The former is the dominant class of soil found on the U.S. IBP Tundra Biome Site 4.

Peat soils of the U.S. IBP Tundra Biome wet mesic meadow sites were characteristic of cold, continental and wet coastal tundra. They were seasonally inundated during snow melt and melt water runoff. The soils were slightly to strongly acidic, with a low base status and low temperatures. They were classed as reducing soils. The soils also had moderately high carbon-nitrogen ratios and were perennially frozen beneath the 20 to 40 cm active layer (Gersper, Arkley, Glauser and Flint, 1974a and 1974b). Gersper et al. (1974a and 1974b) distinguished three principal soil types within this somewhat stratified peat-gley composite. These were fibrists, saprists and hemic soils.

Fibrist (= fibric) peats contain rather raw and fibrous organic matter. They are often cold, water covered and found generally in polygon troughs and drainage slough depressions. They maintain an identifiable organic matter component and demonstrate rather high C:N ratios. The term given to them is cryaquepts.

Saprist (= sapric) peat soils represent the other extreme by having a well disintegrated and decomposed organic matter component. These peat soils are stable, have a low C:N ratio and can be found on polygon rims and raised polygon tops, where soils tend to be less acidic and maintain low soil moistures and higher soil bulk densities.

Figure 17. A 6 inch soil core of the active layer taken to the depth of thaw from meadow tundra. The peat at the right, which adjoins the subsurface silts, may reach 8-10,000 years in age and is only 10 to 12 centimeters below the surface.

Figure 18. The Slough, plot 400, as seen early in the Spring when snow melt water runoff is most rapid and the peat soils beneath are still solidly frozen.

Figure 17. Soil Core of a Cryosaprist Soil Type Taken from Mesic Meadow Tundra, Barrow, Alaska.

Figure 18. Voth Slough and Plot 400, Early Season and Water Covered, Barrow, Alaska.

These soil types are called cryosaprists (Fig. 17). Saprists soils have been examined by others (Drew 1957, Drew and Tedrow, 1957) in the vicinity of Barrow with emphasis on well drained soils of beach ridges.

Hemist (= hemic) peat soils are intermediate between the cryaquepts and cryosaprists. The organic matter was not a 'humus' as found in saprist soil nor was it raw-fibrous. They tended to be dark brown, with an identifiable organic matter component, and found in wet to mesic meadow tundra and in polygon low center basins (Fig. 17). Depth of thaw in the active layer was a function of soil moisture and temperature interrelationships. They not only varied between these three soil types, but they also varied from year to year on individual geomorphic polygonal land forms.

Fibrist cryaquepts of polygon troughs consistantly had deeper mean thaw depths which averaged 31.6 cm in 1972 (Brown, Weber, MacLean, Gersper and Flint, 1974) and 24.6 cm in 1973 (Miller and Laursen, 1974). Saprists ranked second with recorded depths of 25.9 cm in 1972 and 22.3 to 24.5 cm in 1973. Hemists showed thaw depths of 23.7 cm in 1972 and 21.0 to 23.9 cm in 1973.

One characteristic common to all plots on the whole site series was the presence of permafrost. It was a major and dominant abiotic component (Brown and Sellmann, 1973) that laid immediately beneath the active layer. By definition the active layer of 20 to 60 cm is that portion of the soil profile which defrosts annually. It is penetrated by roots of various graminoids and particularly Eriophorum sp. (Shaver, pers. comm.).

Other abiotic parameters vary from plot to plot such as shifts in soil moisture levels. Soil bulk densities also vary. Usually, soil temperatures become variable toward the peat surface or in soils of projecting land forms. All of these interrelated factors collectively influence the microflora.

By definition, permafrost is earth material whose temperature is perennially below 0 C, irrespective of the amount or state of moisture, texture, solidity or lithology (Brown and Sellmann, 1973). At Barrow, and on the peninsula, Brown (1969) and Sellmann and Brown (1965) have demonstrated through coring that actual ice volume pencentages decrease rapidly with depth. There is an increase to about 65 % to 75 % at the 1 m depth. The decline in ice % is rapid thereafter, 60 % at 2 m, 50 % at 3 m, 40 % at 7 m to a low of about 37 % at 12 m. Brown and Sellmann (1973) indicate that permafrost depth in the vacinity of Barrow is 405 m deep with a maximum measurement of 600 m near Prudhoe Bay. Brown and Sellman (1973) also make another interesting point in that ice formed in the permafrost zone is not just interstitial ice. It may take the form of nonvisible films, lenses, massive layers, wedges (Fig. 13) or crystals (Fig. 16) of varying sizes.

Geologically, the peaty coastal plain of middle Arctic tundra near Barrow, Alaska is underlain with Quaternary deposits of non consolidated clay, silt, sand and gravels that penetrate to about 45.7 m. Cretaceous sedimentary rock strata extend below this to about 731.5 m and below this, to unknown depths, is basement rock of Paleozoic and Precambium age.

The general local within which the five intensively studied sites

were located was first described vegetatively by Wiggins (1951) and physiographically by Britton (1966). Britton suggested probable roles of soil types, moisture levels and temperature variations on the development of the plant communities. Billings and Mooney (1968) pointed out that arctic plants were directly affected by the distribution of soil moisture, which controlled local temperature gradients. These physical parameters are, in turn, modified by patterns of snow drifting, wind, and changes in the topography. Sorensen (1941) reported that summer drought in NE Greenland may stop plant growth while temperatures for growth are favorable. The Barrow word model (Brown and West, 1970) describes the Arctic tundra near Barrow as encompassing "a complex of habitats arrayed along a moisture-dominated gradient". The constant shifting of surface features result in very unstable substrates which explains the existance of only one endemic grass species, Arctagrostis latifolia (F. Br.) Griseb. (Hultén 1968). Lists of species compiled for the Barrow area indicate that approximately 126 vascular plants, 155 bryophytes and 75 lichen species have been determined by various investigators (Murray and Murray 1973). It is suspected that approximately 100 or more species of higher fungi will ultimately be described from this same area.

PLOT DESCRIPTIONS

During the summer of 1971, as a field project leader in the U.S. International Biological Programme, I realized an additional need to know and study the associations that fungi maintained with the vascular plant community in Arctic regions and how the fungal component in these regions changed when the plant communities changed. This was the impetus that led me to study and make complete and detailed descriptions of the plant communities found on all respective study plots. My findings are detailed in the following paragraphs.

Most, if not all, plants from each of the 33 plots were collected and identified by me. Voucher specimens and plant specimens for distribution were made. Mr. Leonard Utall, the curator of the VPI & SU herbarium, has sent Arctic vascular plant specimens collected by me to several other herbaria in exchange for plant specimens not previously held at VPI. All fungi, cultures of fungi, and a complete set of Arctic vascular plant specimens from all major collection sites described within this dissertation are maintained at the VPI & SU herbarium. Identifications of algae, lichens, mosses, horsetails and angiosperms were varified by botanists in those areas. For the most part those other botanists were also involved in IPB studies at Barrow.

The VPI herbarium presently contains North America's largest collection of Arctic fungi, a result of over nine years of combined efforts of Dr. Miller and myself.

These fungi came from a variety of plot types from various locations along a moisture gradient transect (Fig. 11). A series of 33

plots of varying sizes were developed so as to encompass specific physiographic features (Table 2). These plots were staked and sampled during the 1972, 1973 and 1974 seasons. Not all plots were sampled all three years. However, 16 of the 33 plots were instrumental in the study and were sampled during the three year study. Plots were selected from seven regions. These seven regions were characterized as: inundated slough (Figs. 18 and 19); low profile wet meadow tundra (Fig. 20); low profile and flat polygon tops comprised of mesic meadow tundra (Fig. 21); polygonal systems having troughs of varying widths, depths and drainage patterns (Figs. 22 and 23); polygon rims of varied heights, slope, dip as well as north-south and east-west aspect (Fig. 24); polygon tops of varying heights (Figs. 25, 28 and 29), under a variety of plant community types; and as low-centered polygon basins (Figs. 26 and 27). The 1400 m moisture gradient transect passed through all 7 regions. Several vegetative differences were noted along this transect. The first of these regularly sampled transect plots was the slough.

Plot 400 (Figs. 18 and 19), a $6m^2$ plot, was located in the Footprint Lake drainage, which was referred to as Voth Slough or Footprint Creek. Early in the season the slough was under several cm of water. Water movement across this plot often exceeded .3 m/sec. with the melting of winter's snow and ice accumulation in the spring. Increased water temperatures resulted from seasonal warming. Thaw of the active layer to a 20-30 cm maximum in the vicinity of Barrow resulted from the seasonal warming. Average thaw depth for 1973 was 26.2 cm (Table 3). The slough plot remained under water until late July. Water depth

TABLE 2

STUDY PLOTS, CHARACTERIZATION AND YEAR SAMPLED ON US IBP TUNDRA BIOME SITES NEAR BARROW, ALASKA

Site	Plot Number	Characterization	Year Sampled
100		Shallow polygon trough; Hot pipe control; Sedges.	1973
101		Hot pipe experimental; Wet meadow; Sedges.	1973
138		Oil applied, 5 liters/m^2; Fertilized 20-10-10, 400 lb per acre; Meadow.	1972
150		Oil applied warm, 20 liters/m^2; Fertilized 13-16-10, 500 lb per acre; Meadow.	1974
151		Control; Fertilized 13-16-10, 500 lb per acre; Meadow.	1974
152		Oil applied, 25 liters/m^2; Fertilized 13-16-10, 500 lb per acre; Meadow.	1974
153		Oil applied, 5 liters/m^2; Fertilized 13-16-10, 500 lb per acre; Meadow.	1974
200		Low flat polygon top; Grass-sedge.	1973
311		Oil applied 12 liters/m^2; Sedge meadow.	1972
400		Voth Slough (Footprint Ck.); Aquatic grasses, mosses.	1972 & 73
414		Wet meadow; Sedge-grass.	1972 & 73
415		Wet meadow; Grass-sedge.	1972 & 73
416		Raised, flat polygon top; Lichen-willow-sedge.	1972, 73 & 74
417[1]		Raised, flat polygon top; Lichen-willow.	1972 & 73
418		Polygon trough; Aquatic mosses.	1972 & 73
419		Raised, uneven polygon top; Grasses and sedges.	1972 & 73
420[2]		Low centered polygon basin; Barren.	1972 & 73
421		North face of polygon rim; Grass-sedge.	1972 & 73
422		Polygon ridge; Grass-sedge.	1972 & 73
423		South face of polygon rim; Grass-sedge.	1972 & 73
424		Polygon trough; Aquatic mosses and sedges	1972, 73 & 74
425		North face of polygon rim; Grass-sedge.	1972 & 73
426		Polygon ridge; Grass-willow.	1972, 73 & 74

[1]Plots 417-419 were an E-W concatenation.

[2]Plots 420-428 were an N-S concatenation.

TABLE 2 Continued

Site	Plot number	Characterization	Year Sampled
427		South face of polygon rim; Willow-grass.	1972 & 73
428		Low centered polygon basin; Barren.	1972, 73 & 74
430		Low flat topped and willow covered polygon.	1972
440A		Peat scar; Dredging perturbation along Voth Slough.	1972
440		Polygon trough cooperative.	1973
441		Polygon rim cooperative.	1973
442		Polygon low center basin cooperative.	1973
450		Beach ridge, high centered grassy polygon top.	1972
1232		Beach ridge, high centered grassy polygon top.	1973
1233		Beach ridge, high domal polygon.	1973 & 74

Figure 19. The lowest habitat, which is inundated early and late in the season, was characterized by dense swards of Arctophila fulva, an aquatic grass, and Eriophorum russeolum, one of three cotton "grasses".

Figure 20. A wet meadow tundra plot, only mere centimeters above the slough shown above, that is characterized by grasses and principally Dupontia fisheri.

Figure 19. Voth Slough and Plot 400, Late Season Spongy, Barrow, Alaska.

Figure 20. Plot 415, U.S. IBP Site 4, Barrow, Alaska.

receded with melting, recession of the active layer and the runoff of melt water. The peat remained soggy and spongy under foot even during the driest seasons. Vegetational cover consisted primarily of scattered aquatic mosses, Calliergon richarsonii (Mitt.) Kindb. ex Warnst., Calliergon sarmentosum (Wahlenb.) Kindb. and Drepanocladus exanulatus (B.S.G.) Warnst. (Rastorfer, Webster and Smith, 1973a, 1973b and 1973c) that fill surface depressions. One dominant species of grass, Arctophila fulva (Trin.) Anderss., and two dominant sedges, Carex aquatilis Wahlenb. and Eriophorum russeolum Fr., comprised the majority of the vascular plant assemblage. These three species, one grass and two sedges, often existed in dense swards. Occasionally patches of black exposed peat were found interspersed throughout the grass and sedge swards. This plot was the moisture gradient's wet extreme and comprised in part the drainage system for Footprint Lake and the surrounding tundra. Until mid to late July the water table on this plot was above ground level. The water moved slowly. By late July, depending on precipitation, the water table often receded below ground level, but a marshy condition was omnipresent. When the plot was in a "dry" state, interspersed patches of saturated black peat became exposed. Low rising lenticular domes predominated between the moss filled depressions and the bare peat. These domes supported the dominant grass and sedge species and these species reflected a true aquatic habitat. There was a noticeable absence of lichens, a marked reduction in the number of vascular plant species, an abundance of mosses and only two fruiting fungi Coprinus martinii Favre ex Orton and Myriosclerotinia sulcata (Whetz.) Buckwald.

TABLE 3

1973 SOIL DEPTH OF THAW IN CM

Plot	Julian day[1]										
	166	169	179	189	199	209	219	229	234	249	267
100					26.0	28.5	31.0	34.0	32.0	35.0	
101					28.0	34.5	49.0	54.0	54.0	57.0	
200	F[2]	5.5	12.0	21.0	22.0	24.0	27.0	24.0	26.0	29.0	
400	F	8.5	15.0	20.0	29.0	29.5	24.0	30.0	25.5	54.0	
414	F	6.0	13.0	20.0	20.0	20.0	22.0	22.0	26.0	23.0	32.0
415	F	5.5	12.0	17.0	20.0	20.0	22.0	25.0	26.0	24.0	31.0
416	F	F	9.5	17.0	21.0	22.5	25.0	26.0	27.0	30.0	30.0
417	7.5	10.0	11.0	14.5	17.0	14.0	24.0	25.0	27.5	25.0	24.0
418	F	4.0	19.0	18.0	22.0	26.0	27.0	29.0	30.5	30.0	19.0
419	6.0	6.0	9.0	14.0	18.0	19.0	27.0	27.0	26.0	30.0	23.0
420	F	F	8.5	13.5	16.5	20.0	26.0	25.0	19.5	27.0	29.0
421	F	F	7.0	11.0	15.0	19.0	25.0	23.0	25.0	27.0	25.0
422	F	F	8.5	11.0	15.5	20.0	27.0	27.0	26.5	27.0	32.0
423	F	F	11.5	15.0	24.0	26.0	30.0	32.0	33.5	33.0	31.0
424	F	F	11.0	22.0	29.0	33.0	39.0	33.0	36.0	22.0	20.0
425	F	F	11.0	16.0	26.0	30.0	39.0	38.0	32.0	42.0	35.0
426	8.0	9.0	12.0	17.0	20.0	23.5	27.0	26.0	31.5	32.0	25.0
427	F	5.0	9.0	13.0	17.0	17.0	21.0	22.0	22.0	27.0	27.0
428	F	5.0	13.0	18.0	21.0	22.0	28.0	28.0	29.0	30.0	23.0
440	F	8.0	16.0	20.0	21.0	26.0	29.0	28.0	20.5	36.0	
441	F	6.5	13.0	14.0	19.0	24.5	28.0	28.0	28.5	33.0	
442	F	4.5	14.0	18.0	18.0	21.0	24.0	23.0	27.0	28.0	
1232	10.0	10.5	13.0	15.0	18.0	28.0	23.0	27.0	26.0		
1233	17.0	22.0	30.5	33.0	31.0	35.5	34.5	37.0	36.0	32.0	

[1]Julian day 166 is 15, June 1973.

[2]Frozen.

Soil moisture percent means of 500 % were consistantly high on this plot at the 1-2 cm depth. Soil bulk density means were low, .204 g/m^2. Soil compaction at the time of sampling was recorded for all plots, but only on plot 400, the slough, was there a significant compaction of approximately 23 %. This was taken into account during the counting of mycelial biomass. The peat soils from this plot were loose, unconsolidated and relatively thin as most loose material was carried away with spring flushing. The aquic pergellic cryaquept soils (Gersper, Arkley, Glauser and Flint, 1974a) were composed for the most part of tiller systems of the dominant graminoids and were very coarse.

Plot 414, a wet meadow, was only .12 m above plot 400 yet there were noticeable differences in the plant community structure. This wet meadow was essentially a very wide and shallow polygon trough. Soils were classified as aquic pergellic cryaquepts (Gersper, et al., 1974a). There was a noticeable and more consolidated peat buildup here than was observed on plot 400. Soil bulk densities at the 1-2 cm depth were approximately .095 g/cc. There were corresponding high soil moisture percents too, which averaged 650 %. Depth of soil thaw never exceeded 32 cm and the 1973 average was 20.4 cm (Table 3). These prevailing abiotic influences essentially provided for the almost pure stand of Dupontia fisheri R.Br. Scattered throughout were Eriophorum scheuchzeri Hoppe, E. angustifolium Honck, and Carex aquatilis Wahlenb. C. aquatilis was a ubiquitous species that was also found to inhabit all but the extremely high plots, 450 and 1233, along the moisture gradient. The lichen Peltigera apthosa (L.)

Willd. was common, but only two fruiting basidiomycetes, Naemateloma udum (Sm.) Sm. and Sing. and Omphalina pyxidata (Bull. ex Fr.) Kumm. and Fuhrer, were found. Two prevalent moss species Hylocomium splendens (Hedw.) B.S.G. var. obtusifolium (Geh.) Par. and Dicranun angustum Lindb. (Rastorfer et al., 1973b) were frequently seen.

Plot 415 (Fig. 20), like 414, was also considered a wet meadow habitat. The plot was a low relief polygon top having a poorly defined trough perimeter. Elevationally, it was just 15 cm above the low wet extreme, plot 400, and 3 cm higher than plot 414. Soils were composed of consolidated and water soaked peat. They were classed as aquic pergellic cryaquepts according to Gersper et al. (1974a). The soil type was again reflected in the high soil moisture percents, 670 %, and in the low soil bulk densities of .099 g/cc at the 1-2 cm depth. Soil thaw depth averaged 20.3 cm during the 1973 field season and never exceeded 31.0 cm (Table 3). Vegetational cover consisted of two dominant graminoids Dupontia fisheri R. Br., and Carex aquatillis Wahlenb., and to a much lesser extent Alopecurus alpinus Sm. spp alpinus, Eriophorum angustifolium Honck., and E. scheuchzeri Hoppe. Three Saxifraga species, S. foliolosa R. Br., S. hieracifolia Waldst. and Kit. and S. nivalis L. were found. Other plants common to the plot were Ranunculus nivalis L., Petasites frigidis (L.) French, Stellaria laeta Richards., Cardamine pratensis L. ssp angustifolia (Hook.) O.E. Schulz and Chrysosplenium tetrandrum (Lund) Th. Fr., but they comprised a very small portion of the total flora. Few moss species were encountered, however, the moss carpet understory was expansive. Only two fruiting basidiomycetes, Galerina subannulata

(Sing.) Sm. and Sing. and Omphalina pyxidata (Bull. ex Fr.) Kumm. and Fuhrer were consistantly collected.

Plot 416 (Fig. 21) was a grass-willow meadow and represented the elevational mean with respect to the 1400 meter moisture gradient. It was a low polygon top discretely defined by a shallow trough system. A firm peat layer persisted. The peat surface was never inundated, but was wet in the early season and remained moist for the duration of the season. Soils were classified as histic pergellic cryaquepts (Gersper et al., 1974a) and were characterized by mean soil moistures of approximately 410 %. Soil bulk densities were .224 g/cc. Soil thaw never exceeded 30 cm and averaged 23.1 cm for 1973 (Table 3).

The deep consolidated peat layer on plot 416 supported a well developed rhizosphere. The plot also supported the greatest number of vascular plant species, maintained a thick moss understory and supported an abundance of fruiting fungi. The basidiomycetes were either decomposers of litter, such as Galerina subannulata (Sing.) Sm. and Sing. and Omphalina pyxidata (Bull. ex Fr.) Kumm. and Fuhrer, or mycorrhizal species associated with Salix rotundifolia Trautv. spp. rotundifolia. The fungi and their associations were identified by Miller, Laursen, and Murray (1972) as Cortinarius flexipes Fr., C. huronensis var. huronensis Ammirati, C. mucosus (Bull.) Ricken, and Hebeloma pusillum J. Lange. On the plot the first encountered Salix species, Salix rotundifolia Trautv. spp. rotundifolia, also dominated the plot. Mixed grasses, such as Calamagrostis holmii Lange, Dupontia fisheri R. Br. and Luzula confusa Lindeb., were dispersed among three sedges, Eriophorum angustifolium Honck., E. scheuchzeri Hoppe, and Carex

Figure 21. A mesic meadow tundra plot characterized by a low lying sedge-willow plant community canopy.

Figure 22. A shallow polygon trough plot that separated two high center polygons at the upper reaches of the 1400 m moisture gradient.

Figure 21. Plot 416, U.S. IBP Site 4, Barrow, Alaska.

Figure 22. Plot 418, U.S. IBP Site 4, Barrow, Alaska.

Figure 23. A deep polygon trough, part of an anastomosing trough system between high centered polygons that represent old age in the geomorphic sequence of polygon formation.

Figure 24. A low broad polygon rim (left center) of the east-west cooperative 440-442 plot concatenation located amongst low centered polygons that are young in developmental age and found on site 4.

Figure 23. Deep Polygon Trough, U.S. IBP Site 1, Barrow, Alaska.

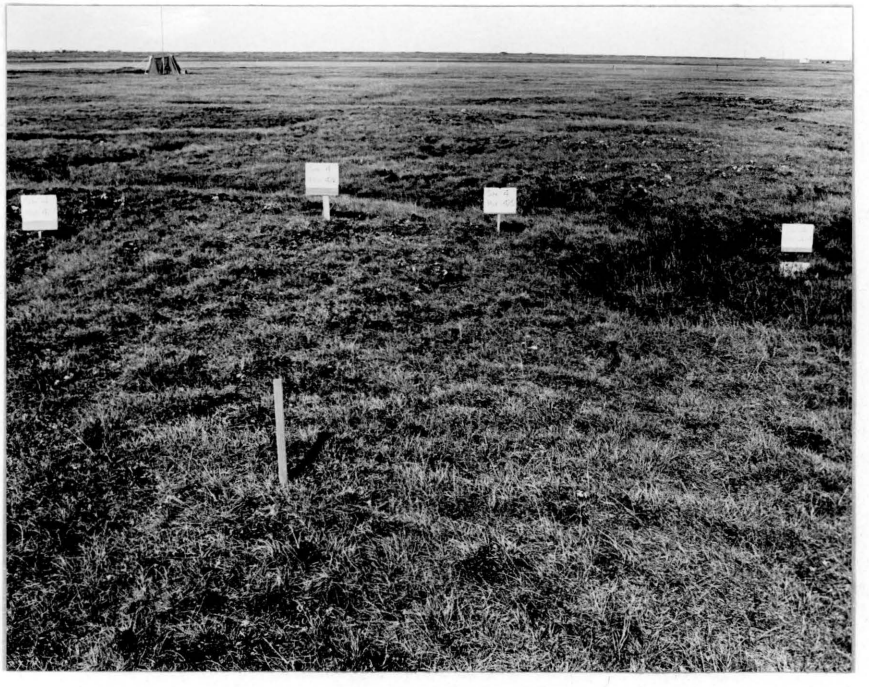


Figure 24. Polygon Rim, U.S. IBP Site 4, Barrow, Alaska.

aquatilis Wahlenb. Low density and often single collections of Saxifraga foliolosa R. Br., S. cernua L., Petasites frigidus (L.) French, and Pedicularis sudetica Willd. were made. Many moss species were found. The dominant species of mosses were Calliergon richardsonii (Mitt.) Kindb. ex Warnst. and Pogonatum alpinum (Hedw.) Rohl. Several lichens such as Cetraria islandica (L.) Ach., C. cucullata (Bell.) Ach., Ochrolechia frigida (Sw.) Lynge, Peltigera apthosa (L.) Willd., Dactylina arctica (Hook.) Nyl. and, what were earlier thought to be two species of Cladonia and now considered one species, C. major (Hag.) Sandst., were also collected by me. Eight species of fruiting basidiomycetes were repeatedly collected, and this represented the greatest diversity of fungi found on any one plot.

The 417-418-419 plot concatenation (Fig. 22) consisted of two high flattopped polygons, plots 417 and 419, that were separated by a polygon trough, plot 418, that was approximately 25 cm deep. The plot sequence was one of two east-west micro gradients along the 1400 m macro gradient.

Plot 417 (Fig. 25) was characterized botanically by ten dominant vascular plant species. The three most common plants were Salix rotundifolia Trautv. spp. rotundifolia, Carex aquatilis Wahlenb. and Petasites frigidus (L.) French. Poa arctica R. Br. was first encountered here by me on the 1400 meter gradient. Nonvascular dominants consisted of five species of lichens and six species of fruiting basidiomycetes. Five basidiomycetes, Cortinarius cinerioviolaceus (Fr.) J. Lange, C. mucosus (Bull.) Ricken, Hebeloma pusillum J. Lange, Russula emetica Schaef. ex Fr. var. alpestris Boud, and Cortinarius

Figure 25. A flattopped high center polygon showing the discontinuous surface of raised peat hummocks that result from the hydrologic freeze thaw cycle. These hummocks and their contiguous depressions provide myriads of habitats for the flora and fauna.

Figure 26. A low centered polygon with 6-10 cm of standing water resulting from snow melt as seen in late June.

Figure 25. Plot 417, U.S. IBP Site 4, Barrow, Alaska.

Figure 26. Low Centered Inundated Polygon Basin, U.S. IBP Site 4, Barrow, Alaska.

flexipes Fr., were found to be mycorrhizal associates with the abundant dwarf willow, Salix rotundifolia Trautv. Galerina subannulata (Sing.) Sm. and Sing., the susptected saprophyte of litter, was abundant too (Miller et al., 1972). The peat layer, a pergellic cryohemist (Gersper et al., 1974a) was 5-6 cm deep. Depth of thaw varied from place to place over the plot's surface. Depth of thaw on this plot during 1973 never exceeded 27.5 cm and averaged 18.1 cm (Table 3). The plot's surface physiognamy of many small moss covered peat hummocks (Fig. 25), whose interstices were filled with organic litter, gave it a characteristic rough appearance. The plot's soil moisture percents of 285 % reflected the gradient's lower values. Soil bulk densities of .22 g/cc were recorded by me. The soil was moist early in the season, but soon dried out as the plot was totally and openly exposed to desiccating winds. Peat was deep and it contained many recognizable plant parts that collected in the hummock depressions.

Plot 418, a polygon trough (Fig. 22), was seasonally inundated both early and late in the season. Its peat layer was 5-6 cm deep and overlaid a 30.5 cm deep active layer. However, mean thaw depth was 22.5 cm (Table 3). Mean soil moisture percents were approximately 625 %. Low bulk densities of .108 g/cc at 1-2 cm reflected the high moisture percents used in delimiting the aquic pergellic cryaquept soil type, also seen on plot 400 (Gersper et al., 1974a). Because of their similarities plots 400, 418, 424 and 440, all basically polygon troughs, were considered together as one convenient habitat type. They had similar soil moistures, bulk densities, particulate matter constitution, and vegetation cover. No fewer than ten angiosperms

were found on this plot. The vascular plant species complex represented a summation of dominant forms also found on plots 400, 414, and 415 excluding only Arctophila fulva (Trin.) Anderss. The two dominant and aquatic moss species were Drepanocladus exannulatus (B.S.G.) Warnst. and Calliergon richardsonii (Mitt.) Kindb. ex Warnst. Two species of fruiting basidiomycetes were found. They were Galerina subannulata (Sing.) Sm. and Sing., a suspected decomposer of humus, and Hebeloma pusillum J. Lange, a documented mycorrhizal former with rootlets of Salix species (Miller et al., 1972). This habitat type was most definitely characterized by its dominant graminoid species Carex aquatilis Wahlenb. and Dupontia fisheri R. Br. Unlike the worldwide distribution of Carex, Dupontia is a nonubiquitous species confined to the coastal north slope region of Alaska and thus is unique to wet meadow tundra under consideration here.

Plot 419, a high, irregular and "grassy" topped polygon, supported a grass-sedge assemblage whose dominant species were Poa arctica R. Br. and Carex aquatilis Wahlenb. The graminoids formed a dense canopy over an even more dense moss carpet understory. Seven other vascular plants, three common lichens, Cladonia major (Hag.) Sandst., Cetraria cucullata (Bell.) Ach. and Dactylina arctica (Hook.) Nyl., as well as three fruiting basidiomycetes, Galerina subannulata (Sing.) Sm. and Sing., Hygrophorus citrinopallidus Sm. and Hes. and Omphalina ericetorum (Fr.) M. Lange, all of which are decomposers, frequent the plot (Miller et al., 1972). An 8-9 cm peat layer covered a 27 cm deep active layer, whose average depth of thaw was 18.6 cm (Table 3). Soil moisture percents ranged from 148.7 % for 1972 to 291.7 % for 1973. Soil bulk

Figure 27. A low centered polygon with a distinct peripheral rim that has been opened and drained by a natural ice wedge that has created a secondary trough.

Figure 28. A high and relatively smooth topped polygon that is located on an old raised beach bench at the extreme western end of the 1400 m moisture gradient transect.

Figure 27. Low Centered Drained Polygon Basin, U.S. IBP Site 4, Barrow, Alaska.

Figure 28. Plot 1232, U.S. IBP Site 12, Barrow, Alaska.

densities of .278 g/cc reflected these lower moistures. Pergellic cryohemist type soils formed hummocky mounds on the polygon's surface. These mounds, surrounded by indentations, were often filled with litter.

Plot 420 is one of nine plots, 420-428, (Figs. 30, 31, 33) that comprised a north-south concatenation within the polygonal system. The sequence was essentially composed of two low center polygon basins, two polygon rims and a deep polygon trough flanked by the two rims.

Plots 420, 428 and 440, all polygon low center basins (Fig. 27), were remarkably similar in most respects. All were inundated both early and late in the season (Fig. 26). Soil moisture percents at the 1-2 cm depth on 420 and 428 ranged from 301 % to 383 %. Plot 440 was wetter at 760 % in 1973. Soil bulk densities at the same depth were low and ranged from .097 to .178 g/cc.

These basins often dried up by mid season during warmer summers (Fig. 27), but remained very soggy with standing water during wet cool summers. The black, bare, and exposed peat surface may be thin or up to 11 cm deep. Depth of thaw, ca 28 cm at its deepest, averaged 20.7 cm (Table 3). Peat layers in these depressed polygon centers were distinct from the subsurface, which allowed the rolling back of the peat mat much as one would a sod turf. The soil type has been described by Gersper et al., (1974a) as a pergellic cryohemist, a soil type encountered again on polygon rims.

Vegetation was sparse. The peat surface was often spotted with a black encrusting lichen Lopadium coralloideum (Nyl.) Lynge, and a white encrusting lichen Ochrolechia frigida (Sw.) Lynge. The predominant vascular plants were Saxifraga foliolosa R. Br. var. foliolosa

Figure 29. The highest and driest polygon top plot was located on the western most end of the 1400 meter moisture gradient, but flagged for ease in relocating from a great distance.

Figure 30. The nine plot concatenation under several cm of snow with only the trough, plot 424, visible in mid June.

Figure 29. Plot 1233, U.S. IBP Site 12, Barrow, Alaska.

Figure 30. Plot 420-428 Concatenation in Late Spring, U.S. IBP Site 4, Barrow, Alaska.

Figure 31. The same nine plot concatenation as seen in Fig. 30, but at mid season, July 10, and snow free.

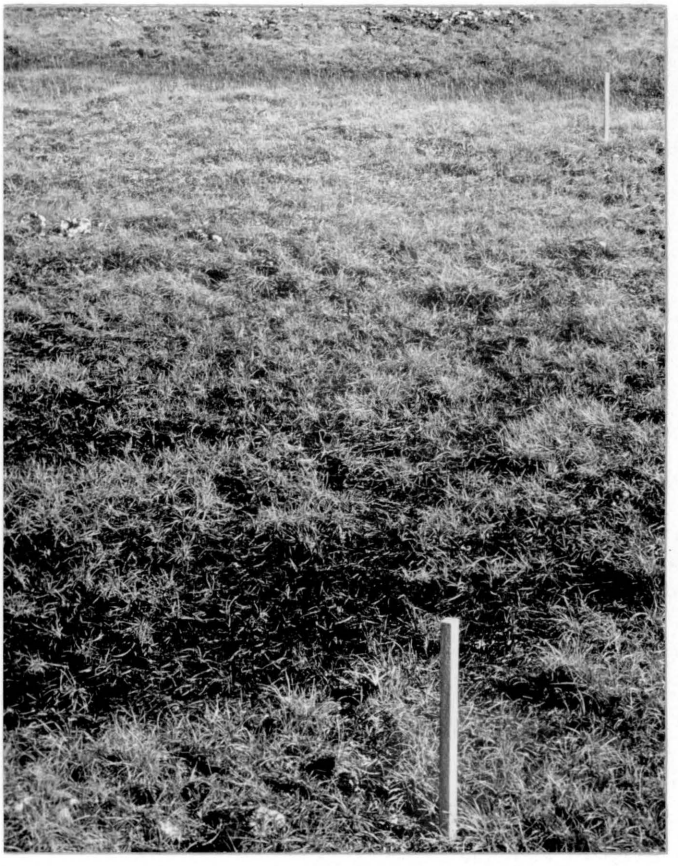


Figure 31. Plot 420-428 Concatenation in Late Spring, U.S. IBP Site 4, Barrow, Alaska.

Figure 32. The three plot cooperative, 440-442, showing the trough, plot 440, on the right, the rim, right of center, and the low centered polygon basin, plot 442, to the left with the white circular lysimeters within.

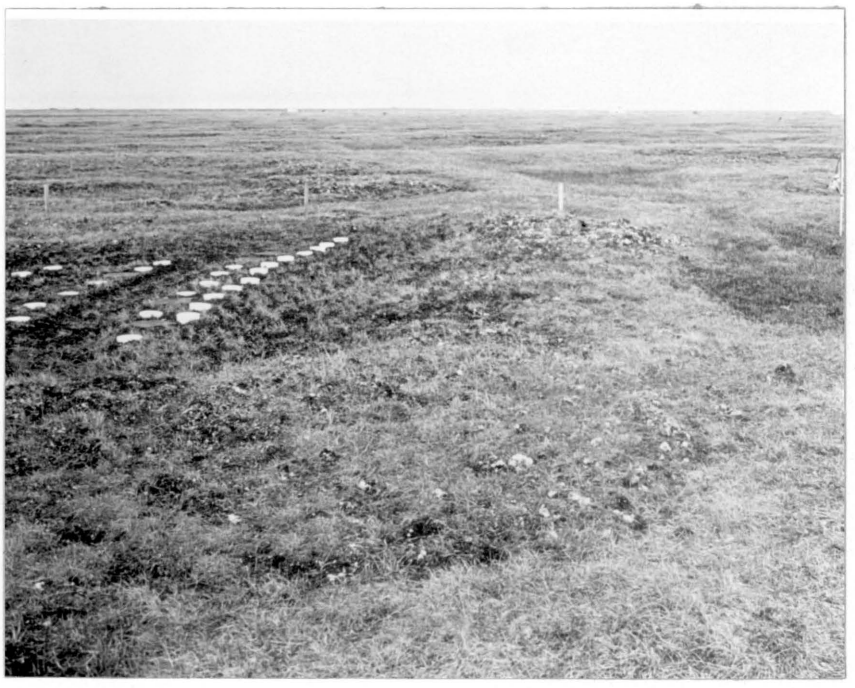


Figure 32. Inter-group 1973 Co-operative Plots 440-442, U.S. IBP Site 4, Barrow, Alaska.

Hultén and Saxifraga cernua L. Carex aquatilis Wahlenb. and Eriophorum angustifolium Honck. were dispersed among the dominant species. Galerina subannulata (Sing.) Sm. and Sing., Omphalina, in the pyxidate complex and a discomycete Aleuria aphanodictyon Kobayasi were higher fungi that were consistantly found.

Plots 421, 422 and 423 comprised the northern most polygon rim in the nine plot concatenation (Fig. 33). Plot 421 was the northern slope of that rim. Plot 422 formed the crest and Plot 423 the southern exposure of that rim. Soil bulk densities were lowest, .162 g/cc, on the north slope, but the same, .23 g/cc, on the crest and south facing slopes. As one might suspect, soil moisture percents were lowest on the crest and ranged from 272.8 % to 367.7 %. They were highest on the south facing slope during both 1972 and 1973 and averaged 352.6 % and 528.5 % respectively. Depths of thaw on the south slopes were not as consistantly deep as those on north facing slopes. But what is even more interesting is that the average depths of thaw on the trough slopes, plot 423 and 425, were 26.2 cm and 29.9 cm as compared to 19.7 cm and 18.0 cm for plots 421 and 427 respectively (Table 3). From all indications, water in the trough had a greater influence on active layer thaw than did the sun's warmth on south facing slopes.

The soil types of all three rim plots were grouped as pergellic cryohemists or sapric types. They were essentially well drained, moist and stable soils with low carbon to nitrogen ratios (Gersper et al., 1974a).

Differences were not so much in the subtle abiotic parameters and

Figure 33. A schematic cross sectional view of the North-South nine plot concatenation showing elevations of the nine plots relative to Mean Sea Level and the low and high plots as well as showing the depths of the peat layer and active layer as actually measured.

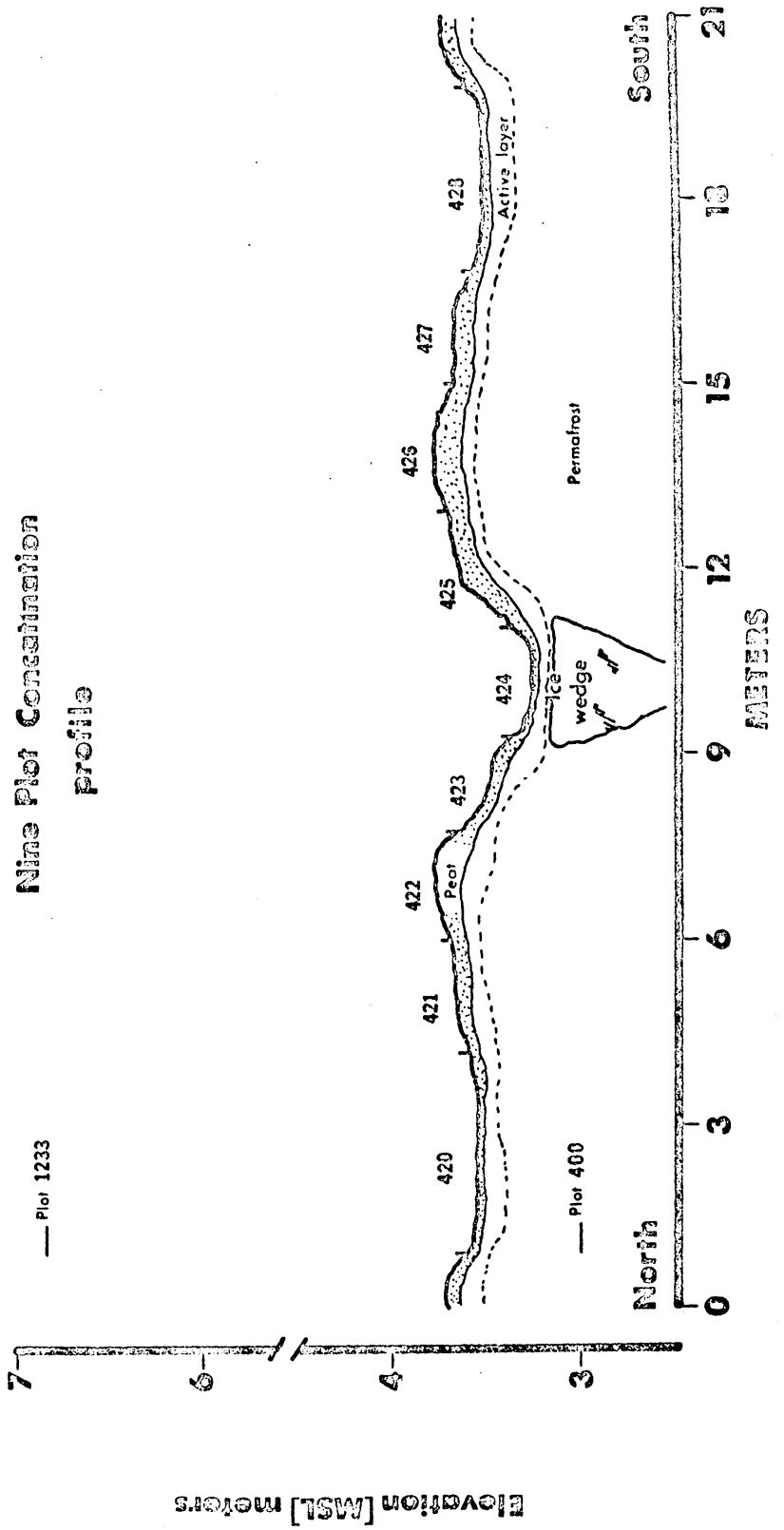


Figure 33. Schematic, Nine Plot Concatenation and Profile, U.S. IBP Site 4, Barrow, Alaska.

slope, strike-dip aspects, but in the vegetation, which seemed to magnify these subtleties. Plot 421 maintained six species of plants with the grammoids Carex aquatilis Wahlenb. and Poa arctica R. Br. predominating. Three lichen species and only one basidiomycete, Galerina subannulata (Sing.) Sm. and Sing., were found here. Plot 422 supported ten species of vascular plants. The dominant species, in addition to the graminoids, was Salix rotundifolia Trautv. ssp. rotundifolia. Four lichens, but only one basidiomycete, Galerina subannulata (Sing.) Sm. and Sing., were found on this plot, which was 6 cm higher than Plot 423. Plot 423 was 13 cm below plot 420, but because of its aspect, drainage and southern exposure, it supported seven vascular plant species dominated by graminoids. No lichens or fruiting fungi were collected during any of the four field seasons.

Plot 424 (Fig. 24), like 418 (Fig. 22) and 440 (Fig. 32), was a polygon trough. The fibric soils contained: high C:N ratios (Appendix 11, Tables 1-3); high soil moisture percents of 728 % to 791 %; low bulk densities of .112 g/cc; and an active layer maximum depth of thaw of 39 cm, which was reached by mid season. The aquic pergellic cryaquept soil type was soft under foot all season. Thaw depth averaged 27.2 cm (Table 3). Just below the thaw zone was an ice wedge that penetrated the permafrost zone to an unknown depth. Early and late season inundation was temporarily relieved by midseason "drying", yet the soil was still wet. The vegetation reflected this perpetual moisture. Eight vascular plant species were found. Dominant were three graminoids, Dupontia fisheri R. Br., Alopecurus alpinus Sm. ssp. alpinus, Carex aquatilis Wahlenb. and two angiosperms,

Cardamine pratensis L. ssp angustifolia (Hook.) O.E. Schulz and Saxifraga cernua L. Three aquatic mosses were also abundant. The dominant moss species were Calliergon sarmentosum (Hedw.) Kindb. and Drapanocladus exannulatus (B.S.G.) Warnst. They were common to this and to other trough plots. Only two fruiting basidiomycetes, Galerina subannulata (Sing.) Sm. and Sing. and Omphalina pyxidata (Bull. ex Fr.) Kumm. and Fuhrer, were found on this plot.

Plots 425, 426, and 427 (Fig. 24), like 421, 422, and 423, represented the north slope, crest and south slope of the southern most polygon rim in the nine plot concatenation (Fig. 33). Soil bulk densities of .427 g/cc were greatest on the rim's crest, plot 426, and lowest on the south facing slope, plot 427, at .176 g/cc. Soil moisture percents were also lowest on the more exposed rim crest, plot 426, and were found to range from 122 % to 200 %. Moisture levels were greatest in soils found on the south facing slope, plot 427, which ranged from 276 % to 419 %. These moisture trends were consistent during 1972, 1973 and 1974. Soil moisture and depth of thaw data from this rim sequence of three plots reiterates the interesting moisture to depth of thaw relationships discussed earlier for plots 421-423. On rim plots 425, 426, and 427 the north facing plot, 425, had the deepest mean depth of thaw of 29.9 cm. Plot 426 thaw depth was 21.0 cm and 18.0 cm on plot 427 (Table 3). The thaw data from this second rim again supports the earlier hypothesis that the influence of sun warmed water covering plot 424 probably transmitted more heat toward the melting of ice in the active layer by not breaking the peat "wick" heat conductor. The result was more rapid thawing of the

active layer, which was faster and deeper penetrating in contrast to thaw resulting from the direct and continuous effects of the sun. It has been observed that "hot" dry weather and warm dry breezes quickly dry surface peat layers. The peat heat transfer or peat "wick" effect is interrupted and thaw rates slow down considerably due to reduced heat conduction. In 1972, a warm dry summer, the depth of thaw was shallowest of any of the four field seasons. Soil depth of thaw was greatest during the "cool" wet season of 1973.

Similar relationships of soil moisture, bulk density and thaw depth were seen when plots were grouped by habitat types. Polygon troughs showed a mean thaw depth of 24.6 cm, whereas polygon tops showed 22.7 cm of thaw, rims 21.8 cm of thaw, meadows 21.2 cm of thaw and basins 20.7 cm of thaw (Table 5). Not a great deal of difference was detected in these mean values, but the maximum value for thaw depth was 27 cm for both slopes most distant from the trough, 32 cm for both rim crests and 39 and 33.5 cm for slope plots nearest the trough.

Plot 425 (Fig. 24) was vegetatively characterized by six species of vascular plants. The dominant species were Dupontia fisheri R. Br., Carex aquatilis Wahlenb. and Eriophorum angustifolium Honck. Five lichen species were also common to the plot, but only one fruiting basidiomycete, Russula emetica Schaeff. ex Fr. var. alpestris Boud., was consistantly found.

Plot 426 (Fig. 24), a polygon rim crest, was similar to plot 422 in that it was an elevated and exposed rim crest, which supported six vascular plant species. Two willows, Salix pulchra Cham. (= Salix planifolia Pursh ssp. pulchra (Cham.) Argus var. pulchra) and Salix

rotundifolia Trantv. ssp. rotundifolia, were the dominant species. Six lichen species, Alectoria nigricans (Ach.) Nyl., Cetraria cucullata (Bell.) Ach., Cladonia major (Hag.) Sandst., Cornicularia divergens Ach., Dactylina arctica (Hook.) Nyl. and Thamnolia vermicularis (Sw.) Ach. ex Schaefr. were common. Nine species of fruiting basidiomycetes, six of which were mycorrhizal formers, and two ascomycetes were collected regularly from this plot. Soils were overlaid by thick, moist consolidated peat of the pergellic cryohemist type (Gersper et al., 1974a). Soil moistures ranged from 83 % to 169 %. Soil bulk densities ranged from .557 g/cc to .588 g/cc and were comparable to plot 422, which was 15 cm below plot 426. Mean thaw depth was 21.0 cm, again comparable to 21.6 cm for other rim crest plots (Table 3).

Plot 427 (Fig. 24), the south facing polygon rim slope, was almost totally covered with mixed Salix rotundifolia Trautv. ssp. rotundifolia and Salix pulchra Cham. The soils, as seen in plots 425, 423 and 421, were sapric soils. They were well drained, stable, with low C:N ratios and described as pergellic cryohemists (Gersper et al., 1974a). Bulk densities of .176 g/cc and soil moisture percents of 276-419 % provided good substrate for six lichen species. Only two basidiomycetes, Hebeloma pusillum J. Lange. and Cortinarius flexipes Fr., were found, and both were mycorrhizal species.

Plot 428 was, for all practical purposes, identical to and only 3 cm below plot 420. Carex aquatilis Wahlenb. dominated the plot. Lopadium coralloideum (Nyl.) Lynge, the most prevalent of the four lichen species, was often found in great abundance. Three fungi, one

ascomycete, Aleuria aphanodictyon Kobayasi, and two basidiomycetes, Galerina subannulata (Sing.) Sm. and Sing., and Laccaria striatula (Peck) Pk., were also found. The pergellic cryohemist or hemic soil type was intermediate in particulate matter and very dark colored. Standing water often had a brown hue to it. Soil moisture percents ranged from 369 % to 484 %. In keeping with the almost saturated soils, low bulk densities of .167 g/cc were measured. The depth of thaw mean was 21.7 cm, which was a little deeper than the 20.6 cm mean recorded for plot 420, but not as deep as the 22.7 cm (Table 3) recorded on plot 442, all of which were low center polygon basins.

Plot 440 (Fig. 32), like plots 200, 441 and 442, was a cooperative interproject plot utilized by most Barrow Decomposer subprogram projects during the 1973 field season. Sampling was destructive. This plot was a 2 m X 4 m polygon trough in a polygon low center, rim, trough concatenation on site 4. The trough was part of a system most of which was inundated troughout the 1973 season. The dominant vegetation was an aquatic moss Drepanocladus uncinatus (Hedw.) Warnst. with sparse Carex aquatilis Wahlenb. dispersed throughout. Soil bulk densities, .212 g/cc, and a soil moistures, 352 %, were comparable to other basin plots. However, no fungi other than Galerina subannulata (Sing.) Sm. and Sing. were found.

Plot 441 (Fig. 32), again part of the cooperative decomposer plot sequence, and sampled only in 1973, was a low flat polygon rim 1 m X 4 m. It dipped gently and had a southern exposure. The white crustose lichen Ochrolechia frigida (Sw.) Lynge was the dominant

lichen species and Dactylina arctica Wahlenb. was occassionally found. Two basidiomycetes, Galerina subannulata (Sing.) Sm. and Sing. and Clitocybe "polygona", a putative new species, were consistantly found here in relative abundance. Saxifraga foliolosa R. Br., however sparse, was the dominant higher plant species on this plot, which was almost completely devoid of vascular plants. A dark and superficially crusty peat was consolidated to about the 15 cm depth. A soil bulk density mean of .226 g/cc and a soil moisture mean of 305 % dry wt. were found. The depth of thaw mean was 21.6 cm, which was comparable to the 21.8 cm overall value for all other polygon rims (Table 3).

Plot 442 (Fig. 32) was the third cooperative decomposer and destructively sampled interproject plot, and was a low centered polygon basin having all of the characteristics of plots 420 and 428. It especially had the thin 4-5 cm turf-like peat mat just above the mineral soil layer. This thin peat layer pealed and was easily rolled away from the mineral soil. The plot was seasonally inundated and supported a sparse vegetation. Soils dried out by late season and became inundated again with precipitation in August. The peat surface appeared black and patchy with bare exposed surfaces having few moss species and only two vascular plants, Saxifraga foliolosa R. Br. and Carex aquatilis Wahlenb. Soil thaw penetrated the active layer to 19.7 cm (Table 3).

Plot 450, like plot 1232 (Fig. 28), was a large flat and grassy topped polygon on the second of four raised beach ridges (Fig. 9). This plot was on the drier portion of the raised beach ridge of site

12, and at the western end of the 1400 m moisture gradient. A peat layer was virtually absent. Instead, a turf of perennial graminoids persisted. The soil was very well drained, a sandy loam, light brown and often referred to as "Arctic Brown". These soil types had the highest bulk densities, .759 g/cc, recorded on the gradient, and were identical to those soils found on plot 1233. The lowest soil moisture percent, 27.4 %, and the deepest average thaw depth, 30 cm, of any plot were recorded here in 1972 (Table 3). Characteristic grasses dominated the flora. Two graminoids, Poa arctica R. Br. and Luzula confusa Lindeb., were intermixed with three showy dicots, Potentilla hyparctica Malte, Petasites frigidus (L.) French. and Papaver lapponicum (Tolm.) Nordh. ssp. occidentale (Lundstr.) Knaben. Few moss or lichen species were collected. One basidiomycete was consistantly found. The caespitose mushroom, Clitocybe sp., formed a "fairy ring" around much of the polygon's periphery. Other fungi found were Hebeloma sp. and a second unknown Clitocybe species.

Plot 1232 (Fig. 28) was another polygonal component of the old beach ridge that paralleled Voth Slough (Footprint Creek). It was a medium high polygon that rose 2.0 m above the slough. The flat top of this plot was slightly depressed and sloped gently to the east. A thick, firm and well developed peat layer supported a well established rhizosphere. Seven dicot angiosperms, one sedge, two dominant grasses, eight lichens, few mosses and one fruiting basidiomycete, Clitocybe sp., characterized this plot. The soils were moist, 168 %, but were substantially lower than the apparent soil moisture dry wt. % optimum of 300-400 %. Soils were dark brown, humic, and of a fine grained sandy

matrix with a bulk density of .4 g/cc. Depth of thaw averaged 19 cm (Table 3). Mycorrhizae were not demonstrated from the vascular plant roots on this plot as grasses were the principal plant inhabitants and mycorrhizal relationships with any of the Arctic grasses or sedges have yet to be demonstrated.

Plot 1233, a domal and deteriorating raised polygon top, (Fig. 29), was the highest plot, 3.82 meters above plot 400, which was the lowest plot on the 1400 m transect. Plot 1233 was also one of the driest plots with an average soil moisture percent of 51.3. The plot was located on the old beach ridge, which comprised the western boundary of the IBP Tundra Biome intensive study sites. A peat layer was dense. The layer formed a thick sod composed of the network of fine fibrous graminoid roots. Fine grained sandy "Arctic brown" soils, typical of those old coastal beach ridges, predominated (Drew, 1957; Drew and Tedrow, 1957). Soil bulk densities averaged .759 g/cc. Soils were well drained and depths of thaw averaged 30.9 cm, the deepest on any plot (Table 3). Plant composition consisted of a few mosses, two lichens, two dominant grasses and five flowering plant species. Poa arctica R. Br. was greatest in abundance. Potentilla hyparctica Malte, Pedicularis kanei Durand ssp. kanei and Stellaria laeta Richards. made the plot quite "showy". The plant composition, and principally the moss species, were indicators of a xeric ridge top habitat (Webster and Smith, pers. comm.). Fruiting basidiomycetes found were Lactarius lanceolatus O.K. Miller and G.A. Laursen, Laccaria striatula (Peck) Pk., and three Cortinarius species including Cortinarius musosus (Bull.) Ricken.

Plots 100, 101, 150, 151, 152, 153, 200 and 311 were experimental or control plots used only during a single season.

Plots 100, a shallow polygon trough on site 1, and 101 were control and hot pipe experimental plots respectively, used in 1973 only. Basic questions were asked concerning the perturbations of tundra with a hot pipe, oil spills and fertilizers, and what if any influence these perturbations had on the population dynamics of soil fungi. Plots 138, 150-153 and 311 were those plots that has been subjected to oil spillage. Plots 138 and 311 were sampled in 1972 and 1974 for below-ground fungal biomass. Plots 150-153 were only sampled during 1974. Each plot had a different type of oil application as well as different quantities of oil dispersed. Plot 200, like 440, 441 and 442, was a cooperative site 2 wet meadow tundra plot and had little significance in this study.

Plot 100 was set up and used only in 1973. It was a shallow, long and narrow polygon trough, 1 X 5 m, that was characterized as mesic sedge meadow. Carex aquatilis Wahlenb. was the dominant vascular plant. There was standing water throughout most of the season over the loose, unorganized, and deep peat layer. This plot was the control to Plot 101, the hot pipe experimental plot.

Plot 101 was a 1 m square plot that was developed and used only during the 1973 summer field season by two projects. It, too, had only a temporary designation. As the experimental plot to plot 100, it had an embedded copper pipe line laid 15 cm below ground level in an "S" fashion. The pipes were parallel and equally spaced at approximately 10 cm apart. Water was piped through the line and kept at

20 C. The initial depth of thaw was 28 cm. After 50 days had lapsed thaw depth penetrated to 57 cm, the deepest recorded on any plot sampled throughout the season. The deeper permafrost thaw penetration resulted in subsidence of the surface (Flint, pers. comm.) so that by 1973 inundation of the plot was constant throughout the season. The peat soil was saturated, loose, unconsolidated and relatively deep. No fungi were found on either of these two plots. They supported rather sparse Carex aquatilis Wahlenb. sedge communities.

Plot 200, a 5 m square flat to somewhat depressed polygon top, was located on Site 2. It was used only during the 1973 field season as a cooperative Decomposer subprogram and interproject plot. Its designation was temporary. The plot represented a mesic grass-sedge meadow habitat typical of site 2. Carex aquatilis Wahlenb. was the dominant vascular plant species. Several lichens were found to inhabit the plot, but two fruticose lichens, Dactylina arctica (Hook.) Nyl. and Cetraria cuculata (Bell.) Ach., dominated. Several mosses were also found, but no fruiting fungi.

Plots 113B, 150, 152, and 153 were designated and treated with various applications of crude oil (Table 2). Plot 151 was the control and was not treated with oil. The plots were sampled by several different investigators at various intervals from 1970 to 1974, and for fungal activity during the 1972 and 1974 field seasons.

METHODS AND MATERIALS

I Belowground Mycelial Biomass

Sampling for belowground mycelial standing crop biomass was initiated in 1972 on a series of 18 U.S. IBP Tundra Biome Site 4 plots (400, 414 to 428, 440 and 450) over a 1400 m east-west moisture gradient (Table 2 and Fig. 11).

The nature of the peat soil, its incorporation of most of the rhizosphere and its approximate depth, were factors used in determining 1 to 2 and 6 to 7 cm depths where sampling was initiated in 1972 and continued for three seasons. However, profile samples were also taken every cm to 7 cm in 1973 and again on select plots to the depth of thaw in 1974. A modification of the Jones and Mollison (1948) technique for determining mycelium lengths allowed for rapid soil preparation, handling, counting and processing. This was necessary because of a short season. Julian days were used (Table 5) to accommodate computer reduction of the data.

Single soil cores were extracted with a core sampler (Fig. 34) by twisting the corer to cut the surface peat and then plunging the corer downward with a quick and forceful push. The author cautions the user of the corer, as designed, when extracting cores from wet soil. Suction may pull the soil core sample from the coring tube as the corer is pulled from wet substrates. The plunger is then used to push the sample core out of the tube. Core samples were placed into 18 oz. Twirl Pac bags for insurance against moisture loss and for transport to the laboratory where they were refrigerated until prepared for fungal biomass, soil moisture and soil bulk density

TABLE 4

PLOTS SAMPLED IN 1971, 1972, 1973 AND 1974 BY HABITAT ON US IBP TUNDRA BIOME SITES BARROW, ALASKA

Meadow	Trough	Rim	Basin	Tops
101	100	417	420	419
200	400	421	428	450
414	418	422	442	1232
415	424	423		1233
416	440	425		
		426		
		427		
		441		

TABLE 5

SAMPLE DATE CONVERSIONS TO JULIAN DAYS FOR 1972, 1973 & 1974

1972		1973		1974	
Date	JD[1]	Date	JD	Date	JD
June 20	171	June 15	166		
June 30	181	June 18	169		
July 2	195	June 28	179		
July 13	209	July 8	189		
July 28	226	July 18	199		
Aug. 11	237	July 28	209	Aug. 19	231
Aug. 25	251	Aug. 7	219	Aug. 29	241
		Aug. 17	229	Sept. 8	251
		Aug. 22	234	Sept. 18	261
		Sept. 6	249	Sept. 28	271
		Sept.24	267		

[1]JD = Julian Day.

Figure 34. An all stainless steel tubular soil corer with removable handles and plunger used during the 1973 and 1974 field seasons for tundra soil core extractions.

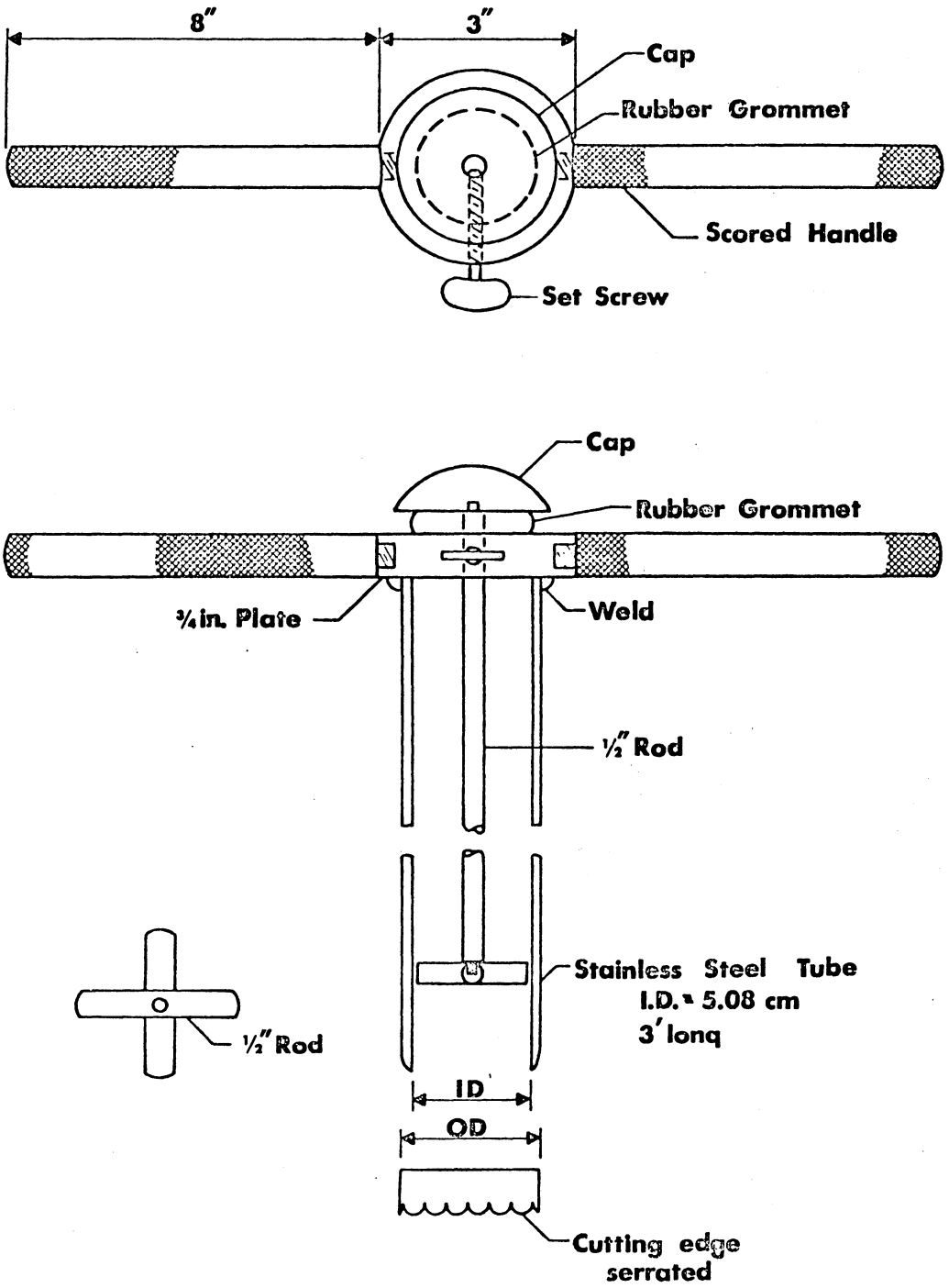
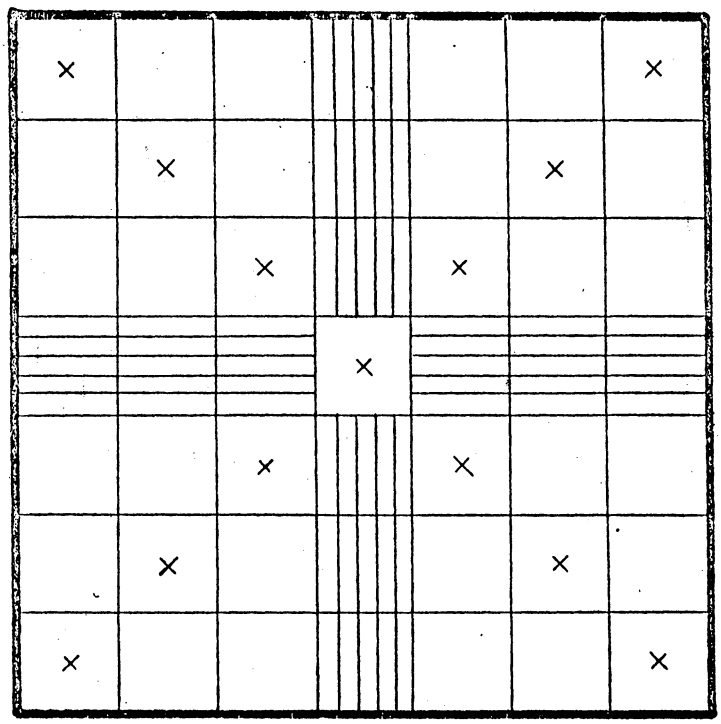


Figure 34. Soil Core Sampler.

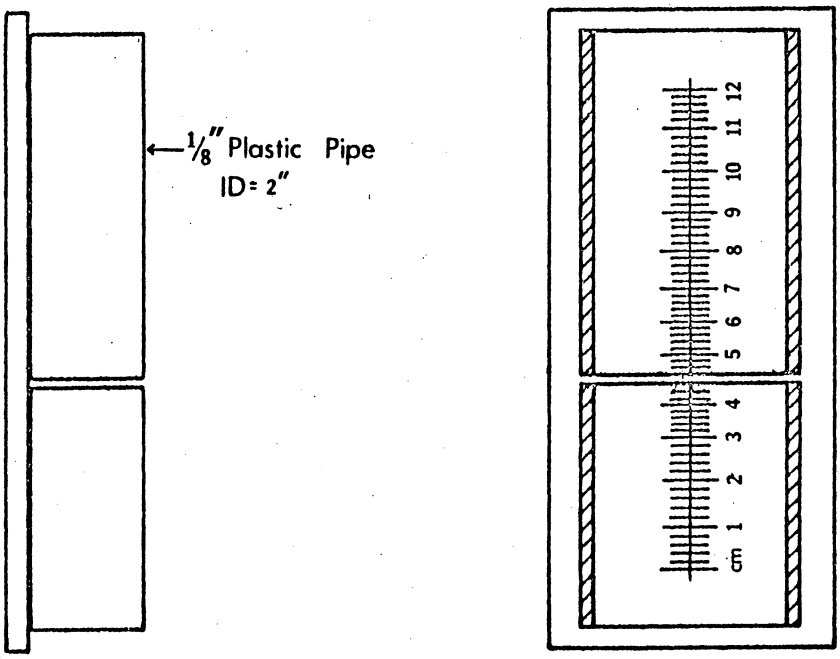
Figure 35. A (127 μm)^2 soil mycelium measuring field seen under 40 X (high dry) as superimposed over the soil agar film. Each square measured circa 20 μm on the vertical and horizontal sides and 30 μm on the diagonal side.

Fig. 35 Fungal Biomass Counting Field



analyses. Samples were taken on a fourteen day schedule commencing June 20, and ending September 6 in 1972. In 1972, 176 samples were extracted over the season from two 'soil' profile depths of 1-2 cm and 6-7 cm and 4,400 microscopic fields (Fig. 35) were examined and the mycelial lengths measured. The plots sampled in 1973 were increased to 24. Sampling commenced on June 15, to determine the level of mycelial biomass frozen *in situ* from the fall of 1972. The 1973 season ended on September 24, at freeze up, in order to ascertain the biomass level at the end of the second season. Eleven samplings were made on a 10 day schedule (Table 5). There were 774 samples extracted, including early, mid and late season profiles, from 0-7 cm. Sample replicates were taken on four select plots: 416; 424; 426; and 428. A total of 40,100 fields were sampled in 1973. Concentration of effort was again confined to the 1-2 cm and 6-7 cm depths in the soil profile. In 1974 only five plots, one representing each of the five habitats, were sampled. Sampling was late season and intensive with five cores taken from each habitat on three sample days. Profiles to the permafrost were taken on two sample days (Table 5). As in 1973, a 10 day sampling regime was adhered to. Sampling in late season was designed to sample biomass levels just before and up to freeze up. Sampling commenced August 19, and terminated September 18, when a frozen surface prevented further sampling. The surface soils were frozen solidly by September 29. There were 267 samples and 13,350 fields examined for mycelial lengths during 1974. The five plots utilized in the 1974 sampling were selected to represent a typical plot in the five habitat types.

Figure 36. An all plexiglass soil core holding and cutting device for cutting 1 cm soil wafers from the soil cores.



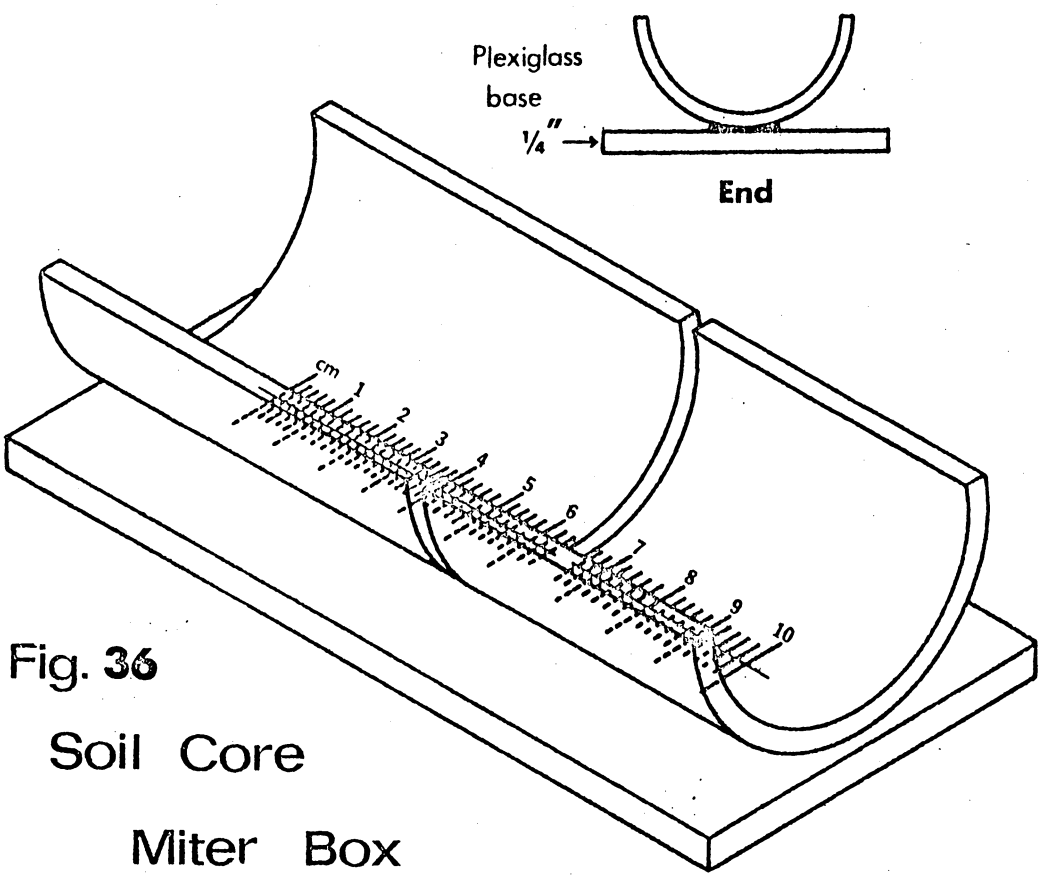


Fig. 36

Soil Core

Miter Box

Figure 40. The grinding process for the 1 cm soil wafers as they were ground through a 1.5 mm mesh aluminum screen prior to the extraction of a 2.5 g sample to be examined for fungal mycelium.

Figure 41. The Jones and Mollison (1948) agar film preparation on blood counting chamber prior to solidification, microscopic examination and measuring.

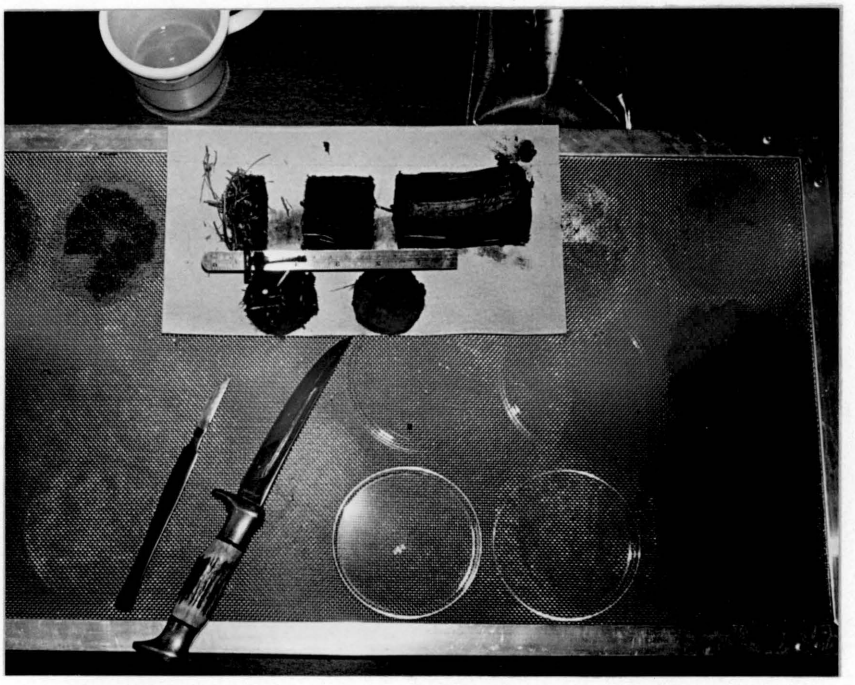


Figure 40. Soil Core Sectioning and Grinding for Biomass Count Preparation.

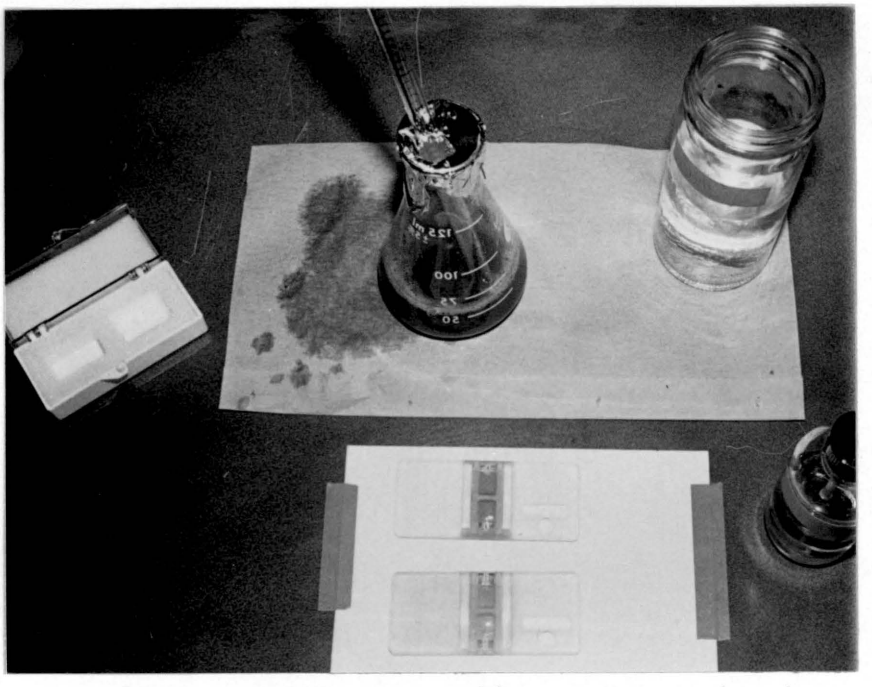


Figure 41. Agar Film Preparation on Haemacytometers.

Throughout the three field seasons of sampling a total of 1217 samples were extracted and 57,850 fields (Fig. 35) were counted for soil fungi.

From each of two soil cores 1 cm soil wafers of known volume were cut from the 1-2 cm and 6-7 cm depths. A thin bladed serrated knife and a slotted semicircular plastic soil core miter box (Fig. 36) were used to section the soil cores. Soil wafers were removed from the two contiguously extracted soil cores at the measured depths during the 1973 and 1974 samplings.

One set of 1 cm soil wafers from each sampled depth was immediately weighed wet, oven dried at 105 C for 24 hours, and reweighed after the soil was cooled for 15 min. Weights were recorded and used to determine soil moisture dry wt. %, wet wt. %, soil bulk density, and g dry soil per m^2 to a 1 cm depth. On a m^2 basis this would be as though a $1m^2$ slice 1 cm deep was extracted from uniform tundra.

From the second core, taken contiguous to the first, soil wafers, which corresponded in depth to those cut from the first core, were similarly cut and removed (Fig. 40). These soil samples were used for fungal biomass determinations using a direct count method.

In preparing the soil samples for biomass determinations an entire wafer from each depth was first ground, using a scalpel, and forced through a 1.5 mm^2 mesh aluminum screen into a 100 X 15 mm disposable plastic petri plate that had been previously marked for that site, plot, date and depth (Fig. 40). Standard aluminum window screen was used, but must be replaced occasionally as it is easily destroyed with continual grinding. The freshly ground samples were immediately

covered and refrigerated at 5 C in an attempt to minimize continued fungal growth. From all freshly ground soil wafer samples a 2.5 subsample, weighed to the nearest 0.1 mg, was removed for the analysis. If a soil contained high densities of mycelium one might want to use less than 2.5 g of substrate. The remaining soil, after extraction of the 2.5 g sample, was retained in the covered and labeled petri plates. These remaining soil samples were wrapped in plastic bags and frozen at -14 C. Soils were later used for the determinations of total soil C, N, and organic matter percents. Freezing will not appreciably affect hyphal lengths because counts from soil before and after freezing were comparable. But, freezing will affect soil moisture significantly through the loss of water by sublimation. It was imperative that soil moistures be determined on fresh core samples because biomass (g/m^2) determinations were based on the soil bulk density. Loss of moisture changes the bulk density and results in drastic changes in fungal biomass. The 2.5 g soil samples were placed into previously marked 2" ID[1] disposable aluminum weighing cans and mixed thoroughly with 10 ml of distilled water. The soil solutions were transferred to a 125 ml Erlenmyer flask prior to preparing the slide for direct measurement of the hyphae (Fig. 41). A non nutritive 2.0 % water agar solution, kept at 50 C in a Thelco Model 83 hot water bath to prevent gelatification, was added to the sample in the 125 ml flask bringing the total volume to 50 ml[2]. The 2.0 % agar, rather than the 1.5 % agar, insured gelatification of the slide preparations when tundra soils with high moisture percents

[1] ID = Inside Diameter.

[2] This is critical as all calculations were based on the dilution.

were used. The soil-water-agar suspension was thoroughly mixed with a glass rod. An A. and O. Spensor Improved Bright-line Neubauer bioassay haemacytometer, 0.1 mm deep, was used to prepare two thin agar films from each soil suspension on each of two cells (Fig. 41). The two celled counting chamber was previously and carefully measured to determine the volume of each cell. More than one chamber was used in the preparations and an average volume of 5.82×10^{-3} cc was calculated. This was based on an area 1/10 mm deep by 8.75 mm long by 6.65 mm wide. Number two $(25 \text{ mm})^2$ cover slips were used because of their rigidity, durability and ease in their removal from the chamber for permanent slide preparation after measurements of mycelium had been completed.

Soil-water-agar aliquots were pipetted onto the haemacytometer with 5 3/4" disposable Pasteur capillary pipettes. Wide mouth (0.7 to 1.0 mm) pipettes were used to prevent "straining" of the preparation. The preheated and filled pipette was placed into the counting chamber's cell "V" notch at the edge of the cover slip. The soil suspension was quickly pulled under the cover slip and filled the 0.1 mm deep cell via capillary action. Preheating the haemacytometer and pipette in the water bath greatly facilitated even and fast flow of the soil suspension onto the slide.

Thomas, Nicholas and Parkinson (1965) suggested that the soil suspension be thoroughly agitated and allowed to settle for 5-10 seconds after which aliquots of the solution were extracted 1 cm below the surface. I incorporated this suggestion into the preparation of each slide because it reduced the possibility of sampling from a

Figure 42. Clamped soil hyphae 2.5 µm in diameter with hyaline walls in amongst other organic debris.

Figure 43. The Leitz Dialux microscope with drawing tube arrangement used for all fungal counts.

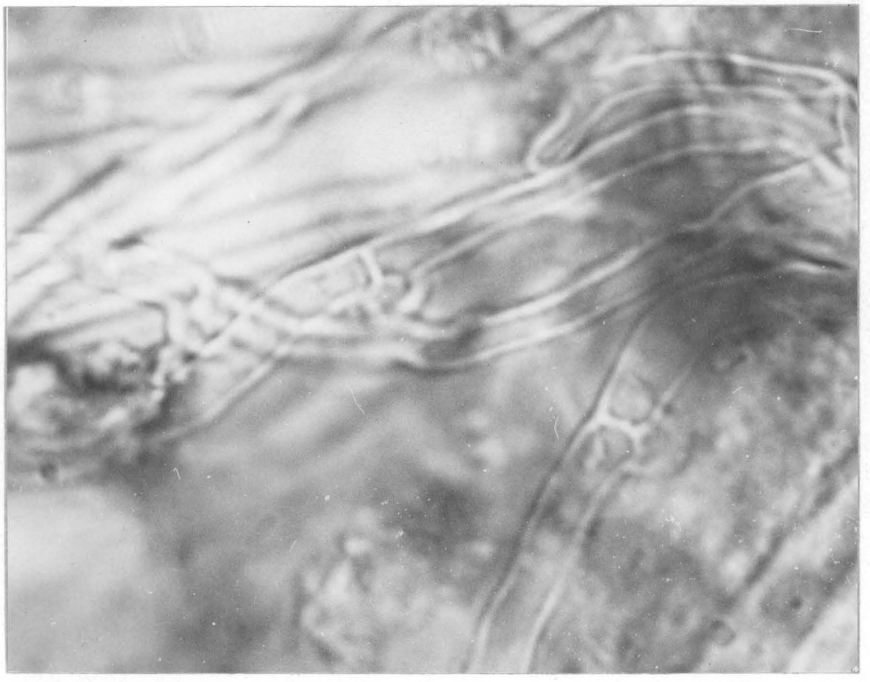


Figure 42. Clamped Basidiomycetous Hypha, x1000.

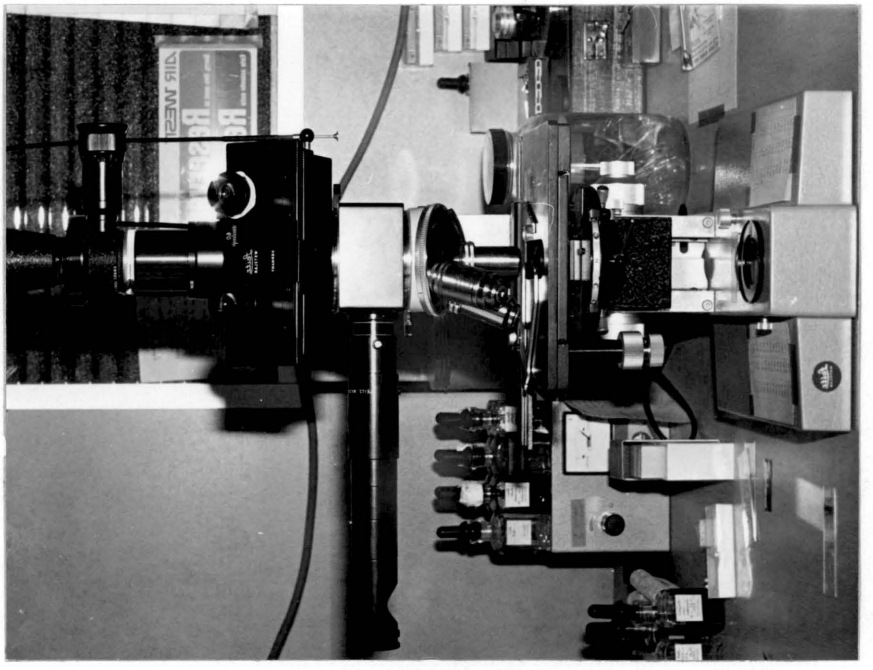


Figure 43. Leitz Dialux Binocular Bright-field Microscope.

suspension level that might have had unnaturally high or low numbers of mycelial fragments that would reflect an incorrect population size. Statistical analyses of similar data taken by Thomas et al. (1965) from top, middle and bottom of the flask containing the soil-agar preparation, and using a pipette with a constricted mouth (.5 mm), showed no significant differences in his final m/gdws calculations.

Measurements of hyphal lengths in microns (Fig. 42) were made from the freshly prepared slides. Slides were observed directly using the high dry (40 X) objective and Periplane 10 X oculars. A Leitz Dialux binocular bright field microscope was used (Fig. 43). Jagnow (1961) used phasecontrast on his stained agar films to discern fungi from actinomycetes and micrococci, and for his measurements. Parkinson, Gray and Williams (1971) claimed that for some soils the use of phase with unstained agar films yielded superior results. Phase contrast was not used in this study, but the light quality necessary to use the drawing tube and the grid overlay created good optical clarity, much like that when using phase. Prepared slides of the agar films were made, but biomass values in this study were always made from the freshly prepared haemacytometer slides.

A table mounted grid field (Fig. 35), patterned after a Whipple disc, was superimposed over the slide preparation by using an attached microscope drawing tube. The superimposed grid was, in effect, a $(127\ \mu m)^2$ field as viewed under 400 X. Twenty-five fields were examined from each cell of the prepared slide for a total of 50 examined fields per soil sample suspension. The decision to count 50 fields was based on the statistical analyses of 4 replicate samples

made in 1972 on plots 416, 424, 426 and 428. The samples counted during 1973 were statistically based on a 36 % error factor at the 95 % confidence level. Accepting a smaller error % would have meant counting several hundred fields per soil sample. A count larger than 20 fields was obviously needed and a compromise value of 50 fields per sample was used in 1973 and 1974. Hyphal lengths were recorded in microns. Permanently mounted slides were prepared from the cover slips by carefully removing the $(25\ mm)^2$ No. 2 cover slips from the haemacytometer with the solidified and intact soil-agar film still attached. The attached soil suspension film on the cover slip was air dried after which a drop of Newcomer's[3] solution was applied and again air dried. The slide was allowed to dry completly and then the cover slip was permanently mounted with a mounting media[4], labeled and retained for later reference. In the removal and preservation of agar films some shrinkage occurred. Therefore, measurements were taken only from freshly prepared slides, and the influences of shrinkage were greatly reduced.

---

[3] Newcomer's Soln.:

	Parts by vol.
isopropyl alcohol	6
proprionic acid	3
petroleum ether	1
acetone	1
dioxane	1

[4] Mounting media:

glycerine 20 ml
dist. H_2O 80 ml
gelatine 3 ml
thymol pinch

heat gently, allow 2 hr. setup.

II Vital Staining

An attempt was made to discern viable and non-viable fungal cells by using a vital stain technique (Barka and Anderson, 1963).

The 2.5 g soil samples from select sample dates, e.g. early, middle and late season, were placed in previously marked 2" ID disposable aluminum weighing cans. The soil samples were prepared and the following were added to each soil sample:

a. M-NBT (M Nitroblue tetrazolium) in Norite water[5] a sensative indicator in a succinic dehydrogenase system adjusted to pH 7.4 using Tris. buffer, 0.6 ml of 2.0 % (2 mg/ml) freshly made stock soln.

b. Sodium succinate, a substrate of 2.0 ml at 0.06 M (16.212 g/l) freshly made stock soln.

c. NAD, coenzyme I, in a phosphate buffer soln., 0.6 ml of 5.0 % (5 mg/ml) freshly made stock soln.

d. Phosphate buffer, 2.0 ml of 0.2 M at pH 7.4.

The 5 ml solution incorporating the above ingredients, was added to the 2.5 g soil sample and the pH adjusted to 7.4 with 1 M Tris. buffer (121.1 g/l DW). The soil solutions were thoroughly mixed and incubated at 30 C for 8 - 12 hours in a Thelco bacteriological incubator. Purple diformizan crystals, which formed around metabolically active sites in the cell, were the indicators of a positive test. In pure culture the reaction was easily demonstrated, where pH adjustment was also very easily controlled. The control of pH in the soil sample was difficult and the result not consistant. Diformizan crystals are also exceedingly difficult to see at 40X. Results

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[5]Norite water is charcoal filtered distilled water using a Buchner funnel and then Seitz filtered three times before use and storage.

obtained were preliminary, and I feel that this procedure may be perfected with additional work.

III Calculations for the Conversion of Sample Data

Calculations of the belowground fungal biomass were made using the VPI computer system and two program languages, Program Language 1 (Pl 1) and the Statistical Analysis System (SAS) (Appendix 12).

Once the two cells on each slide had been counted for total μm of mycelium the data were reduced using the abiotic parameters from the soil system. The result of these data were expressed in the international measure, Meters of Mycelium per gram of Soil (dry weight), m/gdws.

Given:

1. 2.5 g wet soil, agar suspended, where total volume equalled 50 ml;
2. 50 fields per soil sample were counted;
3. calibration of a slide field $(127\ \mu m)^2$ $(.100\ \mu m) = 1.612 \times 10^{-6}\ cm^3$;
4. dry soil 'Z', wet soil 'Y', and water weight;
5. volume of 1 cm core slice = 20.268 cc

R was then calculated:

$$R = \frac{Z\ g\ dry\ soil\ per\ soil\ slice}{Y\ g\ wet\ soil\ per\ soil\ slice}$$

Factor was then calculated:

$$Factor = \frac{50}{(2.5\ g\ wet\ soil)\ (R)\ (1.613 \times 10^6\ cc)}$$

and mean meters of mycelium/g soil (dry wt.) were calculated,

$$m/gdws = (Factor)\ \frac{(X\ \mu m/50\ fields)\ (1\ meter)}{10^6\ \mu m/meter}.$$

The dry wt. biomass (g/m^2) of belowground filamentous mycelium per m^2 was then calculated.

Given:

1. corer inside diam. (ID) + 5.08 cm;
2. vol. core slice (1 cm) = 20.268 cc;
3. "X" µm of mycelium;
4. mean hyphal diameter = 2.75 µm;
5. vol. meter of hyphae = 5.94×10^{-6} cc;
6. specific gravity of mycelium = 1.1 g/cc as experimentally determined;
7. fungus dry wt. = 11.5 % total wt.;
8. wt. meter hyphae = 6.534×10^{-6}g.

The following were calculated.

Soil bulk density;

Fig. 39. $$Sbd = \frac{g \text{ dry soil per soil slice}}{20.268 \text{ cc}} = g/cc$$

Grams dry soil per m^2 to a 1 cm depth;

$$gds = (10^4 \text{ cc}/m^2/cm)$$

Fungal biomass (Fb) standing crop in g/m^2 to 1 cm;

$$Fb = \frac{m \text{ mycelium}}{g \text{ dry soil}} \times \frac{6.534 \times 10^{-6}/g}{m \text{ mycelium}} \times \frac{g \text{ dry soil}}{cc} \times \frac{10^4 \text{ cc}}{m^2 \text{ to 1 cm}}$$

IV Hyphal Widths

Hyphal widths were measured to the nearest 0.1 µm under high dry (40 X) magnification. From each Jones and Mollison slide examined 10 hyphal diameters of clamped and unclamped mycelium were recorded. This was done at the 1-2 cm and 6-7 cm depths and for all profile depths when profiles to 7 cm or to the thaw depth were examined. To insure that only hyphal diameters were being read and not some similar

sized bit of debris a variety of soil types under a variety of vegetation types were carefully examined. It was found that moss rhizoids, several dominant graminoid rootlets, and insect setae were within the 1 to 5 μm diameter range common to hyphal filaments. Certain criteria easily excluded foreign debris, however. Thick and tapering walls of uniform smoothness, no cross walls (septa), the lack of clamps, certain refractive color hues and dark pigmentation were used to discern true hyphae from other similar looking debris. Most hyphae observed were hyaline and thin walled unlike those seen in other peat soils such as those soils from the UK IBP site at Moorehouse and the Ireland IBP site at Glenamoy. Hyphae from soils of these two sites were often thick walled and heavily pigmented (Dowding, pers. comm.)

V Hyphal Growth

The production of fungal mycelium in any soil has never been accurately determined according to Wagner (1974). Early *in situ* fungal growth determinations have been attempted, however, by Rossi, Riccardo, Gesue, Stanganelli and Wang (1936). Rossi et al., (1936) met with varied success as the glass slide technique they used disturbed the natural environment. It was necessary for them to slice the soil for placement of slides. Parkinson et al. (1971) also expressed concern in that moisture condensation on the glass slide might stimulate fungal growth. Other techniques proved to be of equal or little value in early attempts to solve the problem of fungal growth.

In situ fungal hyphae colonization and growth rates were

determined from capillary tube experiments designed by Chester (1940, 1948) and MacWithey (1957) and used by me during the 1973 and 1974 field seasons at Barrow. Another capillary technique described in detail by Peril'ev and Gabe (1969) and Wagner (1974) not only gave good results, but also allowed for easy photographing and measuring of the growing hyphal system.

In my work, sterile 'capillets', 75 mm long and having an inside diameter (ID) of 1 mm, were filled with 6.5 % Sabouraud's Dextrose agar, pH = 5.6. The capillary tubes were placed into 20 X 125 mm screw cap test tubes containing the media. This was done prior to autoclaving. Thus the media and capillary tubes were autoclaved together and the test tube provided a sterile chamber for the filled capillary tubes after being autoclaved. The media containing tubes were allowed to cool. The media level in the upright test tube was sufficiently deeper than the length of the capillary tubes so that all capillaries were totally filled with the media. The sterile agar filled capillary tubes were aseptically extracted from the test tube and transferred to sterile Twirl Pac plastic bags for easy transport to the field for in situ placement. One must use caution in removing the tubes from the agar matrix as negative suction pressures created when extracting the tubes may cause the agar to be pulled out of the tubes.

Tubes were horizontally placed in the peat soil at the 1-2 cm depth in replicates of three. One end of the sterile tube was gently implanted into the substrate so that both peat soil and agar were in contact. This method resulted in little or no desiccation of the agar

because of the relatively high soil moisture percents of coastal wet meadow tundra. Only on one occasion was any desiccation of the agar experienced in Barrow soils. This was on the high dry beach ridge habitat, where soils were sandy loams and soil moisture percents were very low, 20 to 40 % dry wt. Capillary tube implanting was also attempted in a birch-aspen taiga forest (Moore, pers. comm.) with no success as the soil water tension there was too high. The agar completely dried out within a two day period. Tubes in Barrow soils were in place for 15 days with the only noticeable shrinkage of the agar in beach ridge habitats.

Eighteen tubes were implanted on seven plots, which represented typical polygon features of the five habitat types: wet meadow habitats (416); polygon trough habitats (100 and 418); polygon high topped habitats (417); and an experimental hot pipe plot (101). Each placement location was flagged with a disposable plastic pipette marked with brightly colored flagging tape to implement easy retrieval.

Every two days one set of three tubes was removed from each habitat type. They were placed in marked sterile plastic bags and returned to the laboratory for immediate reading. The tubes were read every two days for mycelial invasion and growth under (40 X) high dry. Use of a mechanical stage and a standard glass slide as a backstop for the capillary tube facilitated measurement. Observed hyphal invasions were measured for length in μm along primary hyphal trunks.

VI Colonization and Relative Growth of Soil Fungi

In 1974 experiments were initiated in a taiga birch-aspen forest

(Moore, per. comm.) in an attempt to determine colonization rates of filamentous soil fungi onto an artificial substrate. The in situ substrate used was nylon mesh, 154 meshes per centimeter.

The methods and materials of Moore (per. comm.) were also used to further test and determine colonization rates of soil fungi in wet coastal Arctic tundra peat soils near Barrow, Alaska. The tundra study was initiated late in 1974 during late summer and early fall periods on the U.S. IBP Tundra Biome sites.

The nylon mesh technique was patterened after Waid and Woodman (1957). Their technique was also used by Nagel de Boois and Jensen (1966), and Old and Nicolson (1962). The nylon mesh was cut into $\frac{1}{2}$ X 4" strips. The nylon strips were stretched between the two poles of "J" shaped wire frames made of galvinized steel and sewn with nylon thread around each pole. Frames strung with mesh were placed into the soil with the mesh sandwiched between the soil at the 1-2 cm depth. It has been documented that soil disturbances actually stimulate fungal growth and this fact was considered in placing the device into the soil. Compensation for it was difficult as there was no way to implant the mesh without disturbing the soil.

The mesh was retained in place for 5 and 10 day periods prior to extraction, fixation and microscopic examination. Upon removal from the field the mesh was cut from the wire frame and fixed using 3 % Phloxine, a hyphal stain. A 1 cm^2 section was then cut from the stained and rinsed mesh strip and mounted on a slide for examination. One hundred meshes were randomly selected and observed for fungal invasion. Hyphal presence, and color (hyaline vs. pigmented) were

recorded and percents of colonization were then calculated.

VII C N Combustion Analyses of Fungi and Soil

Fungal cells act to mobilize a certain amount of the available nutrients. Three nutrient elements, carbon, nitrogen and phosphorous, were thought to be held in relatively high concentrations within fungal cells. Dry weight percents of carbon and nitrogen were easily determined via combustion gas chromatography using a 240 Perkin-Elmer Elemental Analyzer. This was done for 19 species that were representative of the more abundant fruiting fungi and were typically limited to specific habitat types. Various portions of the fruiting bodies were tested. Whole basidiocarps, stipe only, cap and gills only or gills only were analyzed. Vegetative cells from in situ sclerotia and in vitro hyphae were also combusted for total carbon and nitrogen. It was also necessary to analyze soil peat substrates. This was done for approximately 100 soil samples, which were taken from the 1-2 cm and 6-7 cm depths on all five habitats, and for soils collected during early, mid and late season for 1972, 1973 and 1974. Soil samples were treated in the same way as fungal samples were for total carbon and nitrogen analysis.

It was desireable to correlate fungal biomass with organic substrate. Organic matter percents (OM %) of a substrate may be determined by ashing methods and gravimetric calculations of the residues produced from sample combustion. Percent total carbon and OM should show a close relationship in soils from the Barrow sites because those soils were highly organic peats. Total soil carbon as

soil C % was therefore used for correlation between fungal biomass and organic matter.

VIII Oxygen Bomb Calorimetry of Fungal Cells

Caloric values for 15 species of Arctic fungi were determined. A Parr Adiabatic Oxygen Bomb Calorimeter was used. The bomb was loaded with one gram fungal tissue pellets at 25 atmospheres of O_2. After ignition the internal parts of the calorimeter were rinsed and the rinse titrated with .0725 N $Na2CO_3$ using methyl red as an indicator. Calories in cal/gdw, (Hg), were determined using the following calculation.

$$Hg = \frac{tW - e_1 - e_2 - e_3}{m}$$

where:

Hg = calories/g of fungus tissue dry wt.
t = temperature ($T_f - T_i = t$)
W = 1351 (Benzoic acid standard, cal/g)
e_1 = ml of .0725 N $Na_2 CO_3$ used in titration
e_2 = (14) (mass of pellet)
e_3 = (2.3) (cm of fuse wire used)
m = mass of the pelleted sample.

RESULTS AND DISCUSSION

I Seasonal Fluctuation of Belowground Fungal Biomass

The results of this work, which were compiled during a three year period 1972-1974, represent the most intensive and comprehensive study of belowground mycelial biomass in Arctic tundra plant communities as ascertained from the available literature, and perhaps from any other single biome worldwide. Barrow IBP Sites can only be sampled three to four months out of the year. The highly organic peat soils of the Barrow Sites do not thaw until mid to late June. They are frozen again by late September or early October. The highest standing crop of fungal mycelium was encountered in the spring, late June. Levels reached 1593 m/gdws in 1972 and 1447 m/gdws in 1973 (Table 6, Fig. 44). Early season data for 1974 was not collected because sampling for fungal biomass during the 1974 season was restricted to late season and to freeze up.

Seasonal progressions showed sharp declines in m/gdws by mid season, July 10-15, of 1016 m/gdws in 1972 and 563 m/gdws in 1973. These declines in m/gdws biomass correspond to: 1) total snow melt; 2) the last flush and drainage of snow melt water; 3) the seasons warmest days and 4) the contraction or shrinkage of the surface peat layer (Flint, pers. comm.). Low biomass levels persisted for 10 to 15 days after which a m/gdws increase was detected. The increase peaked at 1320 m/gdws in 1972 and 949 m/gdws in 1973, but below the early season highs (Fig. 44). In 1972 a leveling in belowground mycelium, m/gdws, was detected at the time of ascocarp and basidiocarp fruiting toward the end of July. This leveling trend of m/gdws was followed by

TABLE 6

METERS MYCELIUM/GDWS FOR 1972, 1973 AND 1974 BY JULIAN DAY AND 1 TO 2 CM AND 6 TO 7 CM DEPTHS

1972			1973			1974		
JD	1 to 2 cm	6 to 7 cm	JD	1 to 2 cm	6 to 7 cm	JD	1 to 2 cm	6 to 7 cm
171	1592.5	704.8	166	346.1	210.4	231	2417.0	256.6
181	1431.5	701.1	169	804.1	468.3	241	871.5	203.2
195	1016.2	389.7	179	1446.9	266.9	251	1762.4	179.5
209	1059.4	292.1	189	932.2	384.6	261	982.1	155.0
226	1320.3	413.6	199	563.3	232.6	271	1824.1	ND[1]
237	1011.3	279.2	209	579.3	158.8			
251	615.3	128.0	219	949.1	230.6			
			229	814.4	297.9			
			234	747.4	212.1			
			249	882.0	231.1			
			267	739.2	521.5			

[1]No data.

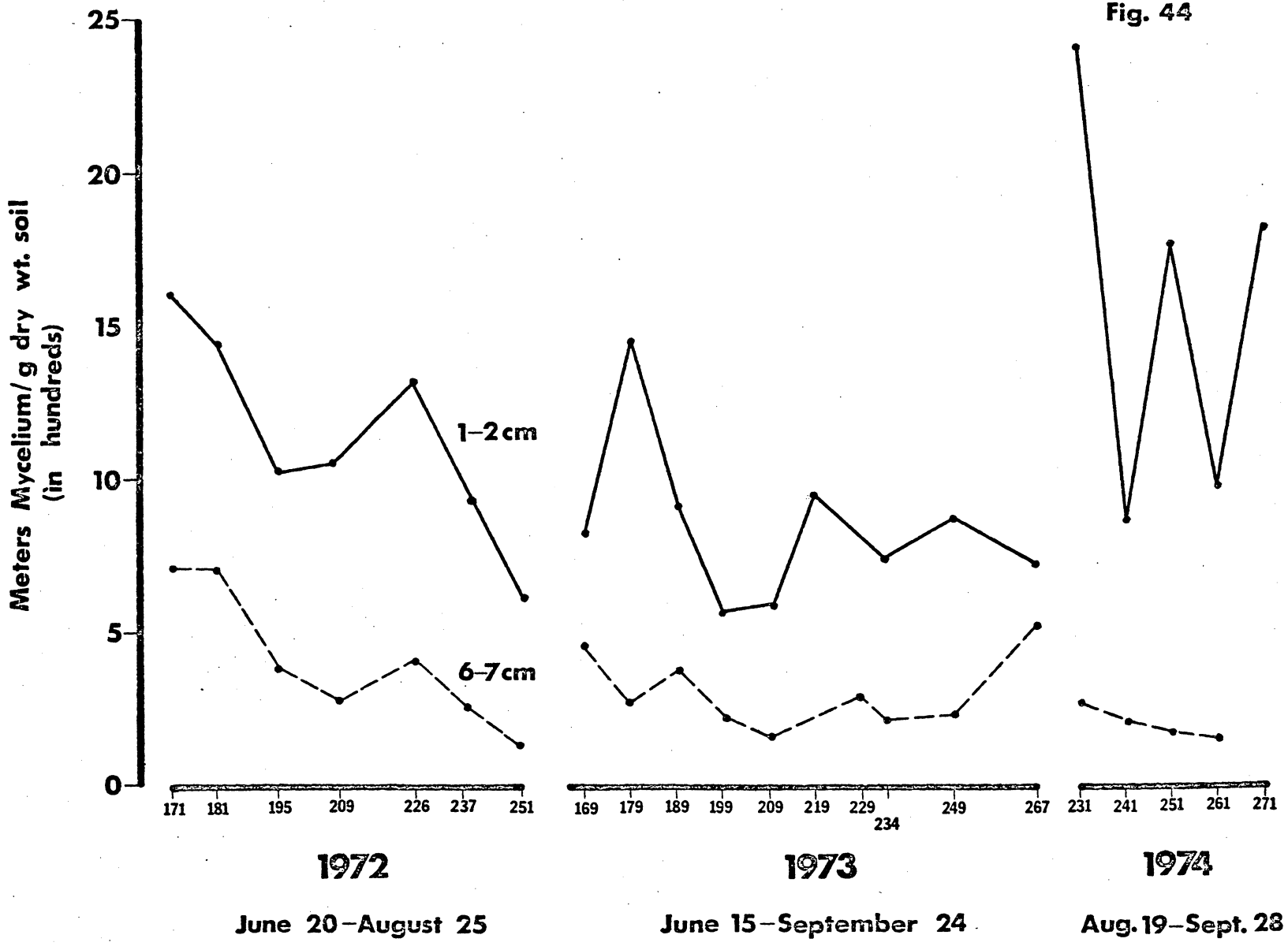
TABLE 7

GRAMS MYCELIUM/m^2 FOR 1972, 1973 AND 1974 BY JULIAN DAY AND 1 TO 2 CM AND 6 TO 7 CM DEPTHS

1972			1973			1974		
JD	1 to 2 cm	6 to 7 cm	JD	1 to 2 cm	6 to 7 cm	JD	1 to 2 cm	6 to 7 cm
171	2.62	2.09	166	1.16	.85	231	3.72	1.78
181	1.75	1.85	169	1.52	1.11	241	1.85	1.33
195	1.91	1.45	179	1.65	.76	251	3.25	.70
209	1.75	1.21	189	1.31	.83	261	3.04	.79
226	1.98	1.05	199	.88	.86	271	2.36	.64
237	1.87	.78	209	.91	.61			
251	1.02	.43	219	1.62	.63			
			229	1.31	1.05			
			234	1.42	.83			
			249	.97	.46			
			267	.69	1.08			

Figure 44. Mean meters of mycelium/gdws for all plots showing seasonal fluctuation in a given year at two depths in the soil profile, 1 to 2 cm and 6 to 7 cm.

Fig. 44


Meters Mycelium/g dry wt. soil (in hundreds)
25
20
15
10
5
0
1–2 cm
6–7 cm
171 181 195 209 226 237 251
169 179 189 199 209 219 229 234 249 267
231 241 251 261 271
1972
1973
1974
June 20–August 25
June 15–September 24
Aug. 19–Sept. 28

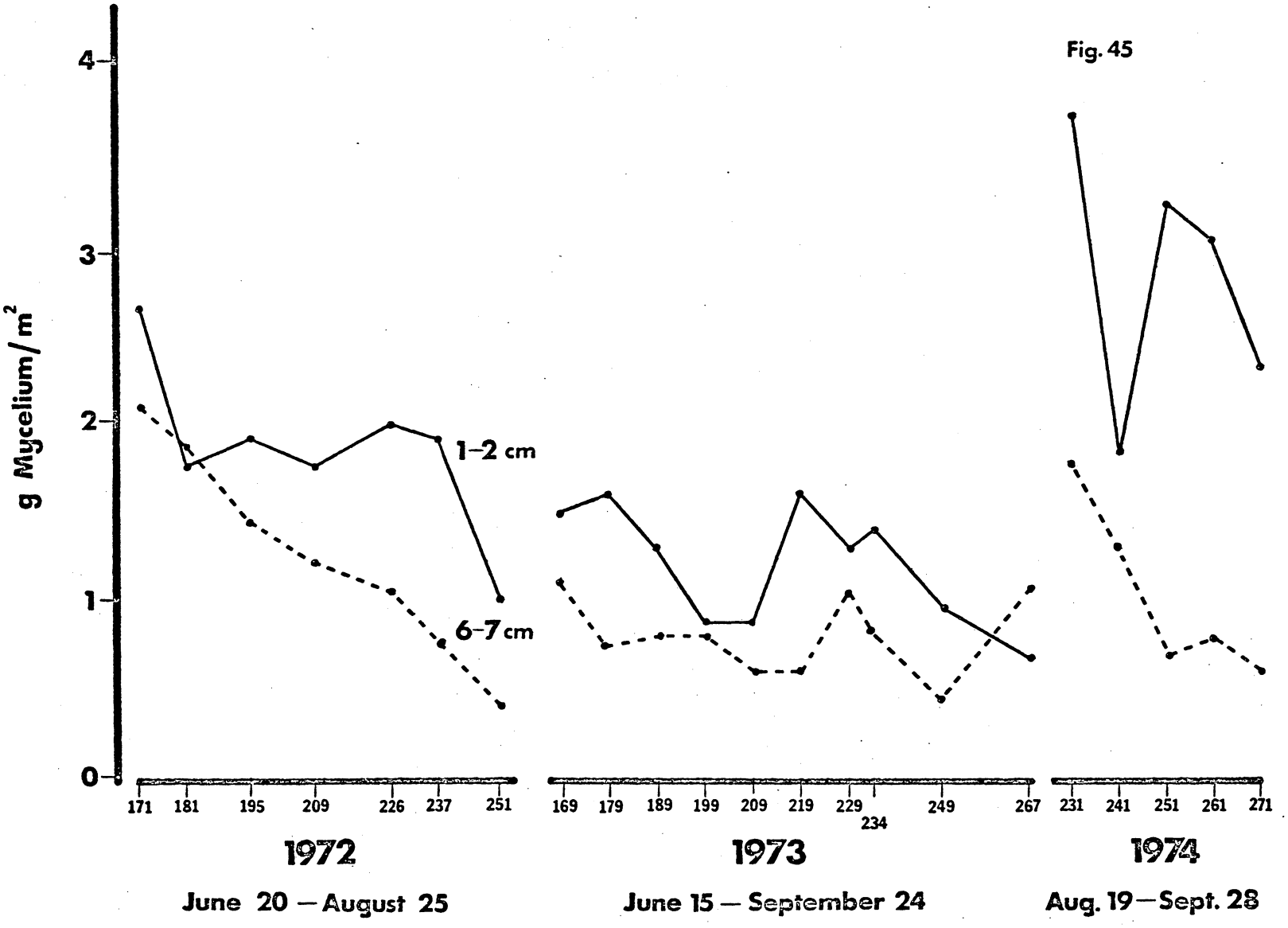
a decline of the belowground fungi, m/gdws, extending into August and to freeze up. A slight increase in m/gdws was observed in early September of 1973, and was perhaps stimulated by additional moisture (Fig. 44). Data from 1974 show sharp declines in belowground mycelial lengths by late August with an abrupt increase in early September followed by a general decline to a 28 September freeze up. The active layer began to freeze from the surface down, even though the subsurface layers continued to thaw (Kessler, pers. comm.). Eventually, thaw rates at lower depths equilibrated and slowly the subsurface peat began to freeze upward. Samples were taken in late season when the soil had already frozen to 1-2 cm. Slight increases in fungal mycelium below 2 cm occurred between Julian day 249 and 267 during 1973 (Table 6). Once the surface was frozen to a 3-4 cm depth, sampling ceased.

This generalized picture of seasonal fluctuation in belowground fungal biomass, as seen in the vernal highs, mid season lows, increases to fruiting and decreases to freeze up, was evident at both the 1-2 cm and 6-7 cm depths where belowground m/gdws counts were concentrated. Fluctuation was, however, less pronounced at the 6-7 cm depth and thought to be the result of less dramatic change of both biotic and abiotic parameters with the increased depth. Soil moistures, soil bulk densities and temperatures tended to be more consistant at 6-7 cm depths.

There was a reduction in the fluctuation of mycelial biomass at 6-7 cm depth as seen in Fig. 45. Fluctuations in m/gdws at the 6-7 cm depth tended to parallel the mycelium fluctuations at the 1-2 cm depth

Figure 45. Mean grams of mycelium per square meter of all plots showing seasonal variation in a given year at the two soil profile depths, 1 to 2 cm and 6 to 7 cm.

Fig. 45


g Mycelium/m²
4
3
2
1
0
1–2 cm
6–7 cm
171 181 195 209 226 237 251
169 179 189 199 209 219 229 234 249 267
231 241 251 261 271
1972
1973
1974
June 20 — August 25
June 15 — September 24
Aug. 19 — Sept. 28

throughout the season. The m/gdws fluctuations were not as pronounced at the 6-7 cm depths as those found at the 1-2 cm depth as shown in Fig. 44. The 1972 season was a dry hot summer and sampling ceased in late August. A steady decline in m/gdws from an early August fall peak to the last sample date is shown in Fig. 44. In 1973, a wet cool year, sampling was continued into mid September. A substantial increase from 230 to 520 m/gdws was detected late into the season and just before freeze-up. During 1974, a rather substantial late season fluctuation at the 1-2 cm depth was detected and the data from 6-7 cm was again reminiscent of the values found during the 1972 late season. The m/gdws values for 1974 were averages of five replicates from each of five plots. Each of the five plots represented the "typical" plot within each of the five habitat types discussed earlier. In 1973, a biomass buildup from late fall, JD 261, to freeze-up was observed (Fig. 44), thus setting apart the 1973 end of season data from the 1972 and 1974 end of season trends. By September 28, the last sample day in 1973, the top 4 cm of soil were frozen. The values for m/gdws measured on that date were, without doubt, the level of belowground fungal biomass (m/gdws) frozen in situ that winter.

These same generalized patterns of mycelial biomass fluctuation, m/gdws, were also demonstrated in the Barrow litter layers by Flanagan and Scarborough (1974) and in an old oak-beech forest litter zone by Nagel de Boois (1970) in the Netherlands.

When considering the biomass of belowground fungi, g/m^2, somewhat different seasonal patterns of fluctuation become evident (Fig. 45).

Soil bulk densities must be used to express mycelial biomass in g/m^2. The influences of soil bulk density on mycelial biomass will be discussed in a later section of these results. It must also be kept in mind that soil bulk densities of these peat soils were greatly influenced by temperature and moisture. At the 1-2 cm depth seasonal g/m^2 biomass means paralleled m/g values. The only striking dissimilarity existed between m/gdws and g/m^2 on JD day 169 of 1973 (Fig. 44 and 45) where the g/m^2 biomass fluctuations were substantially lower than m/gdws. Peat soils readily absorb moisture and swell. The 1973 season was wet and even though m/gdws values were relatively high the substrate was soaked. Thus the weight of substrate to a known volume was less in 1973 than was found in 1972 or 1974 because of swelling. Biomass in g/m^2 was therefore less in 1973 than in 1972 or 1974 for an equal volume of soil. This same soil weight to volume ratio also changed with depth because there was a reduction in moisture levels with increased depth. In every instance and during all three years the g/m^2 biomass at 6-7 cm appeared higher than the m/gdws lengths at 6-7 cm (Figs. 44 and 45), but the patterns of fluctuation remained similar. Two data points, one on day 181 of 1972 and the other on day 267 of 1973, were striking evidence that soil moisture profoundly effected the relationships of m/gdws to g/m^2. On these two days the g/m^2 at 6-7 cm actually surpassed that found at 1-2 cm depth even though the m/gdws show opposite trends (Table 7 and Fig. 45). The explanation for this again lies in water content of the peat soil, which will be discussed later.

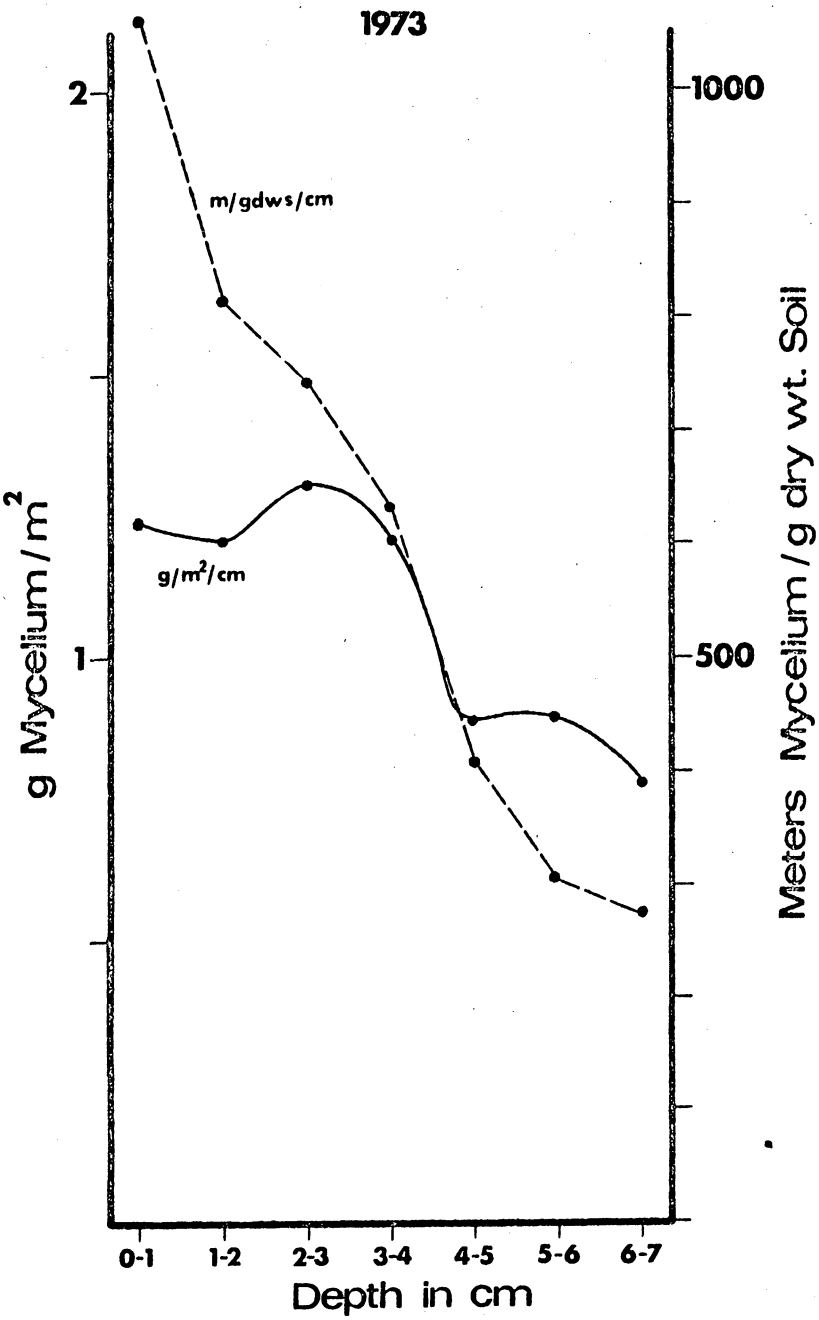
II Spatial Distribution of Fungal Biomass: The Profile

In 1972, biomass sampling was concentrated at the 1-2 cm and 6-7 cm depths. Obvious differences were detected in belowground fungal mycelium, m/gdws, between these two depths during all three years. Not until 1973 were complete 0-7 cm profiles run for mycelium or biomass. Mycelium, m/gdws, and biomass, g/m^2, dropped appreciably with increased depth in 1973 (Fig. 46) and again in 1974. Subtle changes in fungal mycelium and biomass, with small increment increases in depth over a given season, were sought. In addition, it appeared that changes in mycelium were influenced by abiotic parameters within the five habitat types with increased depth. The effects of these influences were also sought. Therefore, it was desireable to develop a profile sampling regime that would meet these objectives. This was done for the 1973 field season and again for the 1974 late season sampling.

In 1973, soil profile cores to 7 cm depths were extracted from all regularly sampled plots on three days as outlined in Table 8a. Samples from these plots were taken during 1973 early, June 28, mid, July 28, and late season, August 22. In 1974, profile cores were again taken, but were cut to the depth of thaw of the active layer.

Depths of thaw within each of the 5 habitat types will vary depending on the temperature and moisture regimes characterizing a particular season. However, thaw will generally cease at about 25 cm, except for beach ridge polygon top habitats where thaw may reach 50-60 cm.

Figure 46. Seasonal means in grams of mycelium per square meter and meters of mycelium per gram dry soil for all plots showing the relationships of grams to meters in the 7 cm soil profile in 1973.


1973
2
1
1000
500
m/gdws/cm
g/m²/cm
g Mycelium / m²
Meters Mycelium / g dry wt. Soil
0-1
1-2
2-3
3-4
4-5
5-6
6-7
Depth in cm

Profile samplings were difficult as the number of samples processed was large due to the fact that each centimeter was examined for mycelium.

Examination of the data revealed a steep decline in fungal hyphae, m/gdws, with increased depth (Table 8a and 8b, Fig. 46). At 5-6 cm a leveling of the biomass was observed with a continued decrease in m/gdws, but at a much less pronounced rate of decline. In 1974, an appreciable increase in m/gdws below 10-11 cm was detected. This increase was associated with a buried peat substrate above which there was a mineral soil layer where mycelium lengths and biomass were always greatly reduced. Of importance was the fact that over 75 % of the total m/gdws were found in the active rhizosphere zone, the top 4-5 cm. Not only were mycelium in m/gdws greater in the top 4 cm, but so was the seasonal fluctuation of mycelium as depicted in Fig. 47. The greatest fluctuation was detected early between vernal highs and mid season declines. Magnitudes of seasonal fluctuation were most pronounced between 4-5 cm and 5-6 cm depth as seen in Fig. 48. It also becomes apparent that mycelium of soil fungi in a tundra ecosystem were largely restricted to the top 4-5 cm. In contrast to the narrow life zone of tundra communities was a life zone many meters deep in a temperate ecosystem where soil fungi have been detected at depths of 90 cm (Doxtader, 1972).

Averages for fungal mycelium during the early, mid and late 1973 season were 931, 404 and 387 m/gdws/cm respectively for Barrow. Steady declines with increased depth become apparent from the data in Table 8a as graphed in Fig. 46. Because of increased soil bulk

TABLE 8a

1973 MYCELIUM PROFILE MEANS IN A 1CM WAFER 1m ^{2} TO A DEPTH OF 7CM BY DEPTH-DAY[1]

Profile depths[2] in cm	Overall means	m Mycelium/g dry soil		
		June 28 JD 179	July 28 JD 209	August 22 JD 234
1	1063.5	1544.9	757.6	888.1
2	814.7	1446.9	579.8	747.4
3	742.5	1252.8	417.3	557.5
4	632.7	1096.5	367.0	434.6
5	357.8	559.4	270.7	252.3
6	302.8	346.2	279.2	285.0
7	273.0	266.9	158.8	212.1

TABLE 8b

Profile depths in cm	Overall means	g Mycelium/m^2		
		June 28 JD 179	July 28 JD 209	August 22 JD 234
1	1.24	1.53	.92	1.29
2	1.21	1.64	.91	1.42
3	1.31	1.67	.80	1.47
4	1.21	1.59	.81	1.23
5	.89	1.01	.69	.98
6	.89	.77	.81	1.09
7	.78	.76	.61	.83

[1]Depth-day means include all plots (24) on the US IBP TB Site moisture gradient, Barrow, Alaska.

[2]Profile depth 1=0-1cm, 2=1-2cm, etc.

density and decreased soil moisture percents with increased depth, fungal biomass shows 1.28, .79 and 1.12 g/m^2/cm. There was no steady decline with increased depth through the 1973 season (Fig. 46). The data in Table 8b represents what was found in 1973 on the three sample days for the 0-7 cm profile. It shows what has become a characteristic increase in biomass, g/m^2, between the 1-4 cm depths (Fig. 49). Decrease in fungal biomass, g/m^2, was most pronounced in the 1-5 cm depth throughout the 1973 season on the three sample days. An increase in biomass was actually detected from mid to late season at 5-6 cm (Fig. 49). Biomass, g/m^2, at depths greater than 10 cm declined slowly throughout the season as was detected in the 1974 profiles taken to 25 cm depths. The increase in biomass of fungi at 2-4 cm in 1973 corresponded nicely to the depth of the majority of vascular plants roots with which several of the basidiomycetes form the mycorrhizal association. Fungal biomass, m/gdws and g/m^2, became relatively constant with some fluctuation from 8-24 cm depths as was detected in 1974 profile data (Tables 6 and 7, Appendix 9). However, the amplitudes of fluctuation seen at depths greater than 10 cm was relatively small. An increase in m/gdws with increased depth was again noticed from soil cores taken to a depth of 60 cm at the NARL Mead River camp 60 miles south of Barrow. Mycelium, m/gdws, increased at the 10-12 cm depth. This increase was thought to be due to the deeper penetrating rhizosphere in hummock tundra characteristic of the Mead River camp.

The kind of intense sampling for belowground fungal mycelium done here within soil profiles has not been done elsewhere nor have the

Figure 47. Accumulation in meters per gram of soil as accrued over the entire 7 cm profile depth showing the vernal high, mid season low and end of season buildup with the greatest variation in the top 4 cm.

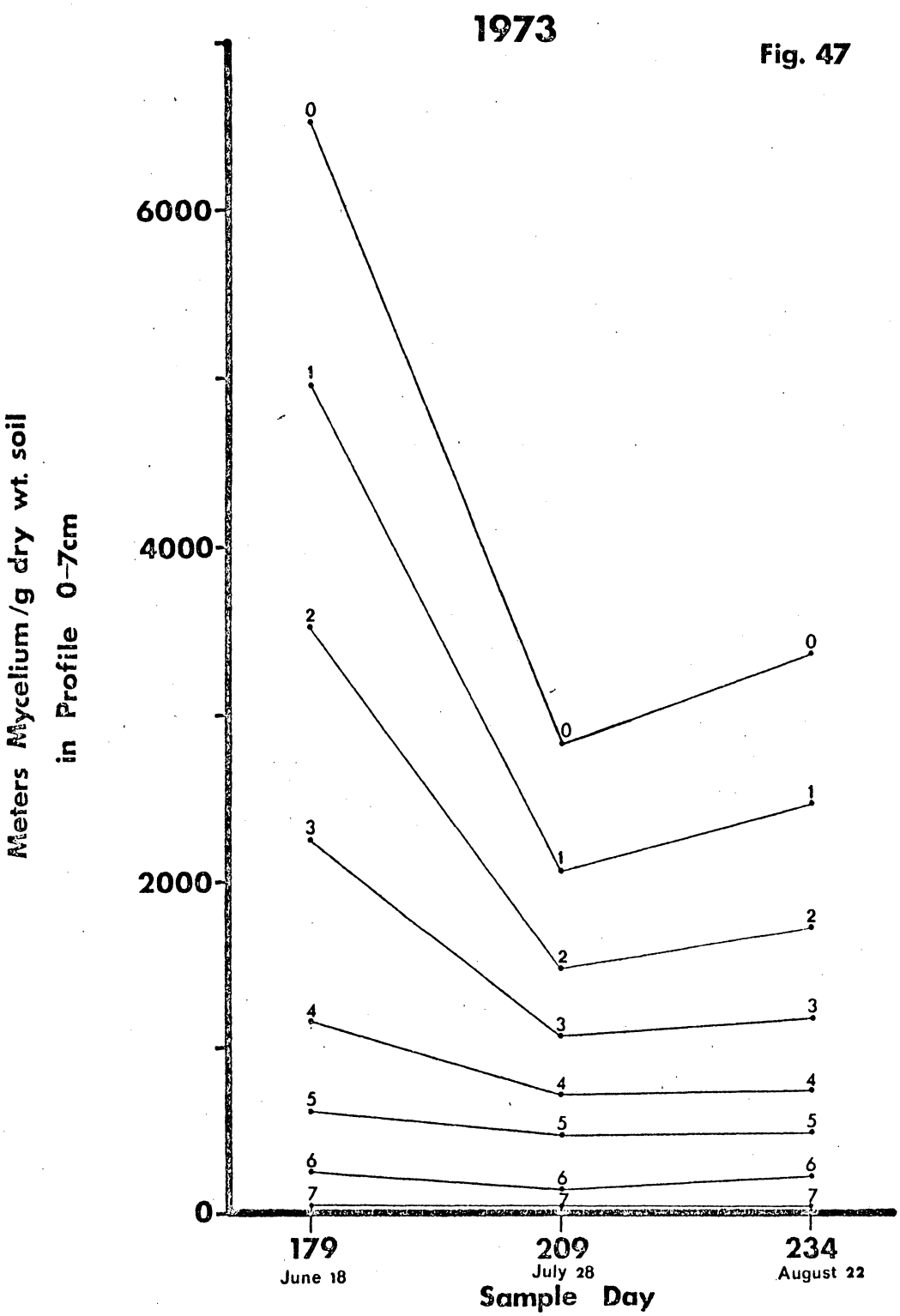

1973
Fig. 47
Meters Mycelium/g dry wt. soil
in Profile 0-7cm
6000
4000
2000
0
0
1
2
3
4
5
6
7
179
June 18
209
July 28
234
August 22
Sample Day

Figure 48. Magnitudes of difference between depths showing the greatest difference in m/gdws occurring between the 4 cm and 6 cm depth throughout 1973.

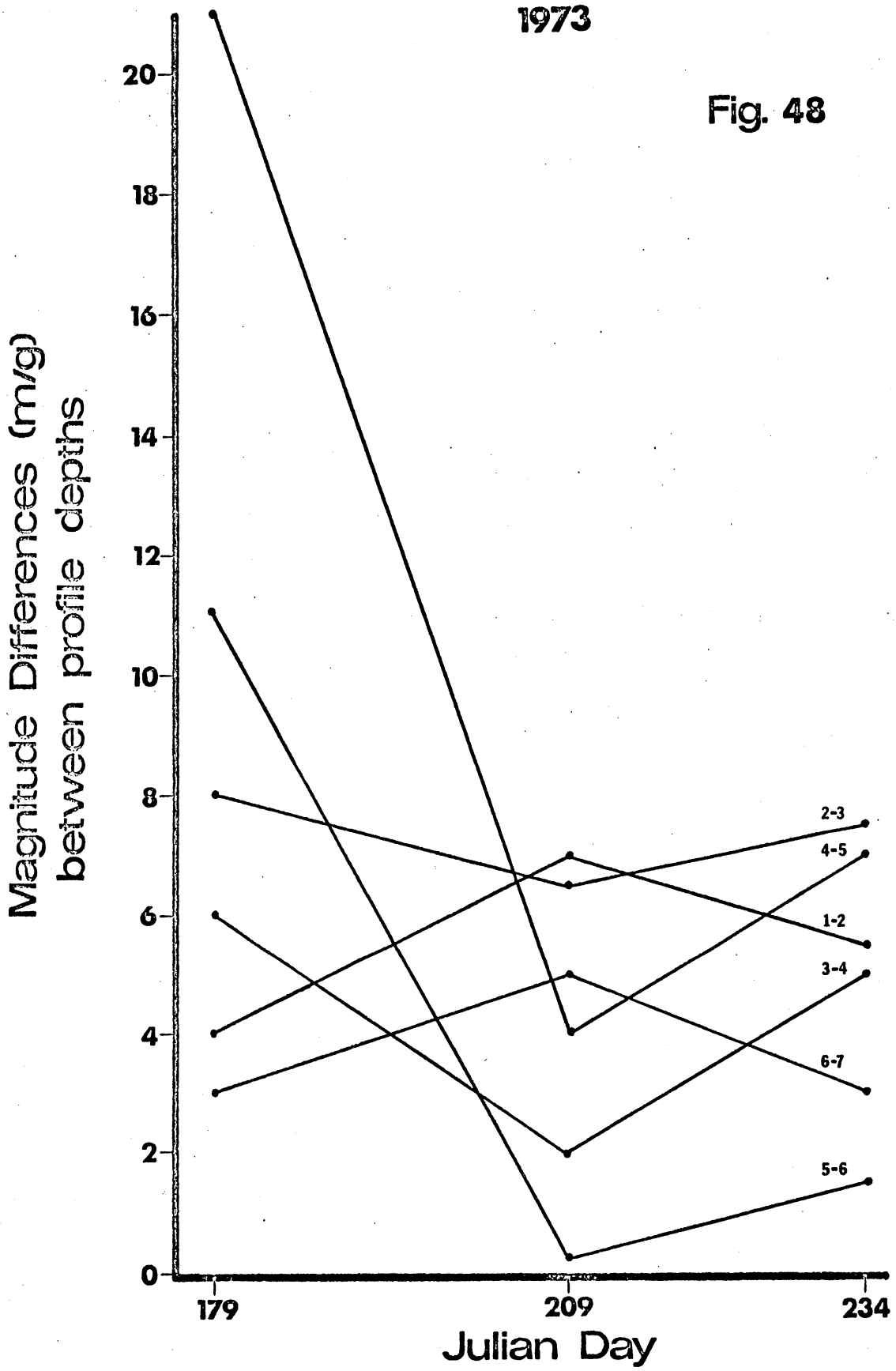
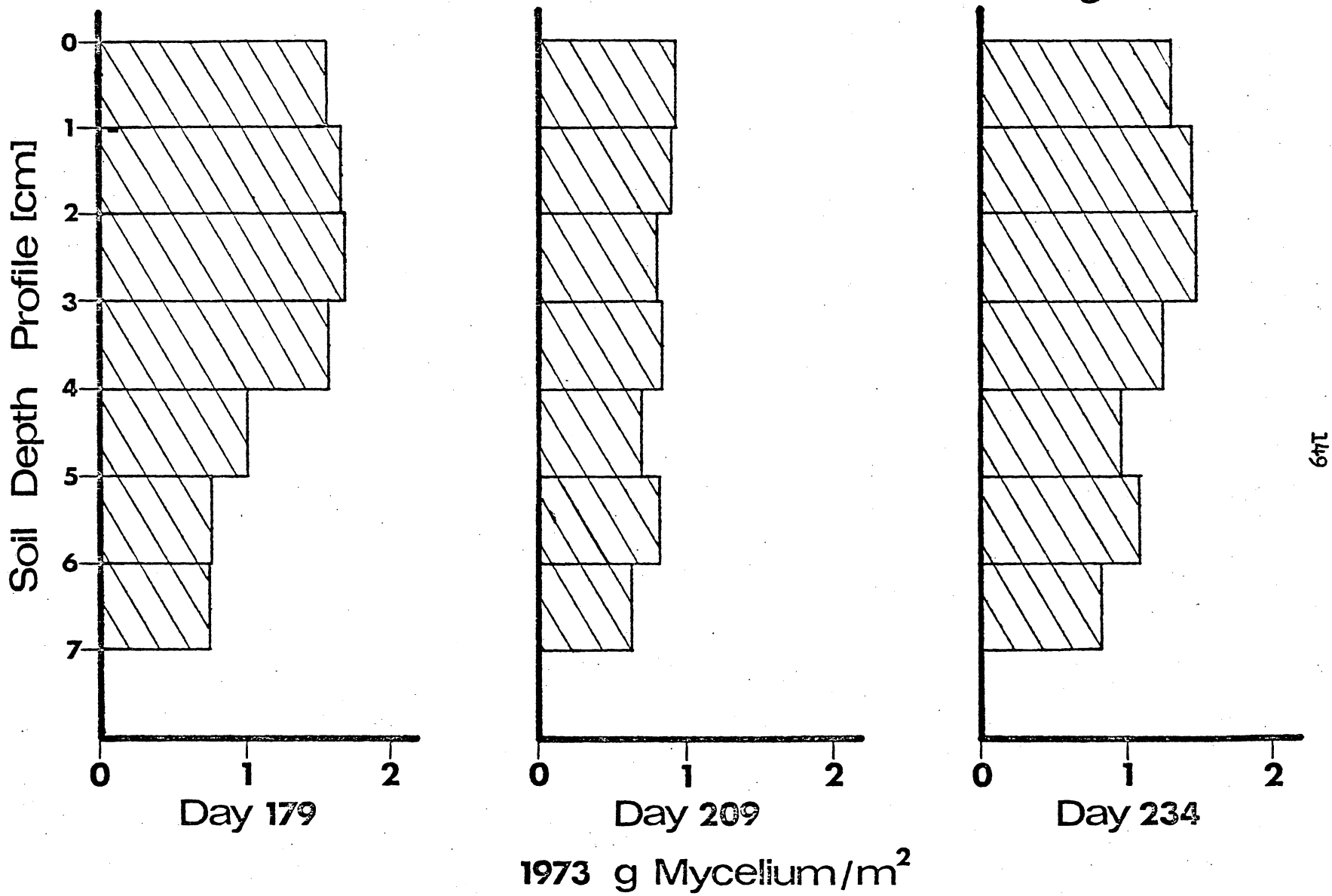

1973
Fig. 48
Magnitude Differences (m/g)
between profile depths
20
18
16
14
12
10
8
6
4
2
0
2-3
4-5
1-2
3-4
6-7
5-6
179
209
234
Julian Day

Figure 49. Grams of mycelium per square meter down through the 7 cm depth soil profile as determined early, mid and late season 1973, and showing the fungal biomass concentration that coincided with the rhizosphere at 1-4 cm.

Fig. 49


Soil Depth Profile [cm]
0
1
2
3
4
5
6
7
0
1
2
Day 179
Day 209
Day 234
1973 g Mycelium/m²

149

population dynamics of belowground fungal mycelium over several seasons been demonstrated for Arctic tundra. It was this knowledge that little profile work had been done that led to intensive sampling in all five habitats of polygon meadows, troughs, rims, basins and tops.

Within each of the five habitats soil profile trends in m/gdws and g/m^2 to 7 cm were found to be similar to the over all trends. All habitats except polygon tops showed early season vernal highs, mid season lows and late season buildups in g/m^2 and m/gdws (Table 9 and 10). Polygon tops had slowly declining mycelium, m/gdws, and biomass, g/m^2, that continued to decline into the late season. In 1973, rim habitats had by far the greatest mean biomass accumulation in g/m^2 with 13.42 $g/m^2/7$ cm followed by top habitats with 5.95 $g/m^2/7$ cm and meadow habitats with 4.83 $g/m^2/7$ cm (Fig. 50). Basin and trough habitats were lowest with 3.72 and 2.85 $g/m^2/7$ cm respectively. All habitats except basins showed characteristic increases in g/m^2 from 1-2 cm (Fig. 50). Basin habitats showed a nice curvalinear decrease in g/m^2 with increased depth. The increase was minimal, however, in trough habitats. Trough habitats showed relatively little change other than a slight increase in biomass with increased depth. The data in Table 11 also suggests that little change in the ordering of habitats by g/m^2 occurred from early to mid to late season. There was no doubt that the greatest accumulation of soil fungi was confined to the upper 4 cm of the soil profile in all five habitat types along the 1400 meter moisture gradient transect.

TABLE 9

1973 BELOWGROUND FUNGAL BIOMASS (g/m^2) EARLY, MID AND LATE SEASON MEANS 0-7CM BY HABITAT[1]

Habitat	June 28 (179)[2]	July 28 (209)	August 22 (234)
Meadow	1.044	.536	.622
Trough	.444	.310	.355
Rim	2.282	1.258	2.367
Basin	.518	.499	.522
Top	1.019	.888	.679

TABLE 10

1973 METERS OF MYCELIUM/G DRY WT. SOIL EARLY, MID AND LATE SEASON MEANS 0-7CM BY HABITAT[1]

Habitat	June 28 (179)	July 28 (209)	August 22 (234)
Meadow	895.7	371.4	472.2
Trough	370.6	191.6	246.7
Rim	1710.6	633.8	776.4
Basin	428.4	304.6	344.2
Top	333.7	236.5	197.3

[1]On US IBP TB Sites, Barrow, Alaska.

[2]Julian day

Figure 50. Grams of mycelium per square meter for each of 7 depths in the soil profiles of five habitats, rim, top, meadow, basin and trough, showing profile relationships of grams of soil fungi to depth.

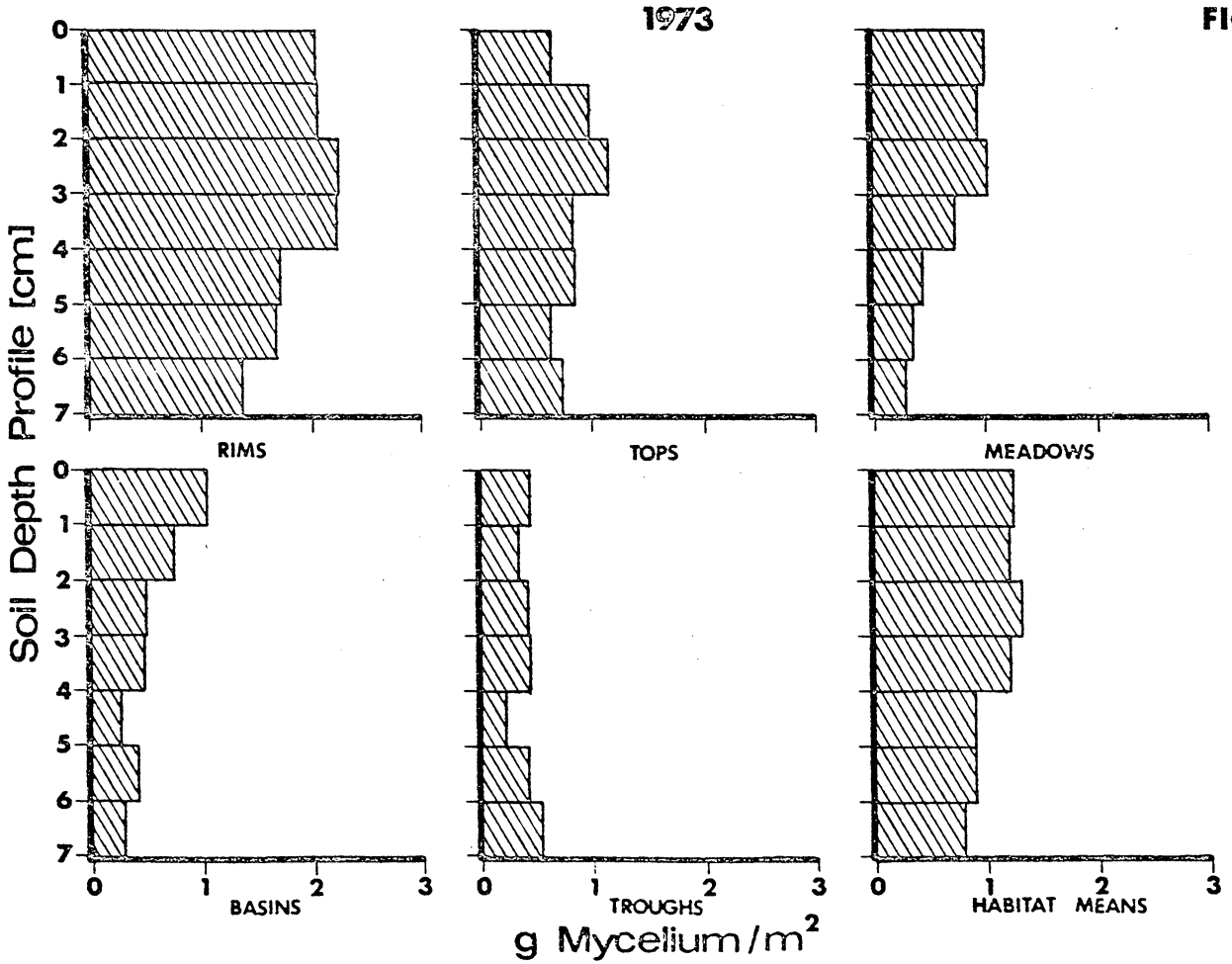

1973
Soil Depth Profile [cm]
0
1
2
3
4
5
6
7
RIMS
TOPS
MEADOWS
BASINS
TROUGHS
HABITAT MEANS
0
1
2
3
g Mycelium/m²

FIG. 50

TABLE 11

1973 BELOWGROUND FUNGAL BIOMASS (g/m^2) DRY WT.

TO A 7 cm DEPTH

Habitat	June 28 JD 179[1]	SM[2]	July 28 JD 209	SM	August 22 JD 234	SM
Rim	14.11	1.22	8.81	1.05	16.56	1.28
Meadow	7.32	1.1	3.69	.82	4.52	.82
Top	7.14	1.05	6.22	.81	4.76	.65
Basin	3.63	.37	3.5	.69	3.66	.55
Trough	3.1	.74	2.19	.43	2.51	.5
$\bar{x}$	7.06	.94	4.88	.73	6.4	1.07
SD[3]	4.39		2.64		5.75	

TABLE 12

1974 BELOWGROUND FUNGAL BIOMASS (g/m^2) DRY WT.

TO A 7 cm DEPTH

Habitat	August 29 JD 241
Rim	29.39
Meadow	20.19
Trough	11.24
Top	7.62
Basin	5.95

[1]Julian day = JD.

[2]Standard error of the mean.

[3]Standard deviation

III Belowground Fungal Biomass Within Habitats

In comparing Figures 51 and 52 certain differences were noted between m/gdws and g/m^2 in all 5 habitats at the 1-2 cm depth. The standing crop of fungal mycelium, m/gdws, was profoundly altered when space, moisture and substrate relationships were considered as influencing variables. The effects of soil bulk density will be expanded in a later section.

In 1973, rim habitats had a mean of 1291 m/gdws/cm (Table 1C, Appendix 7). Basin habitats followed with 580 m/gdws (Fig. 51). Polygon top habitats with 396 m/gdws were close to the 380 m/gdws of trough habitats, and meadows showed the lowest value with 213 m/gdws.

When considering differences in g/m^2, the ordering of habitats into a hierarchy showed characteristic differences as graphed in Fig. 52. The ordering of the habitats, from high to low biomass, showed differences when m/gdws and g/m^2 were contrasted. Rim habitats had the greatest biomass of 2.56 $g/m^2/cm$ or 17.94 g dry wt. to a 7 cm depth. Meadow habitats followed with 1.53 $g/m^2/cm$, or on a dry weight basis a biomass of 10.68 $g/m^2/7$ cm. Trough habitats had 1.01 $g/m^2/cm$ for a total 7 cm dry weight mycelial biomass of 7.07 g. Polygon top habitats had dryer soils of much greater bulk density then the spongy peats of polygon basin habitats and this was reflected in greater biomass, g/m^2, values. Top habitats had .87 $g/m^2/cm$ or 6.1 $g/m^2/7$ cm. Basins were slightly less with .7 $g/m^2/cm$ or 4.91 $g/m^2/7$ cm. In 1973, Trough habitats showed lower biomass in m/gdws and g/m^2 than was found in basin habitats (Fig. 52). The seasons of 1972 and 1974 were both drier than 1973 and the ratios of soil space

to substrate volume were suspected to be responsible for the greater biomass than was found in 1973. The most dramatic difference between m/gdws and g/m^2 during 1973 occurred in soils of rim habitats. Soil bulk density was suspected of being the cause of this rather dramatic change, even though rim habitats maintained the greatest m/gdws and g/m^2 of any habitat.

Season fluctuations of fungal mycelium, m/gdws, within each of the five habitats were similar to overall seasonal fluctuation patterns. Meadow habitats (Fig. 53) and rim habitats (Fig. 55) showed the repeating patterns of vernal highs early in the season. Vernal highs were followed by distinct and abrupt declines in m/gdws to a mid season low. Fungal mycelium increased and then leveled off at a time when basidiomycetes fruited. After the fall fruiting period fungal mycelium, m/gdws, again declined and continued to decline generally to freeze up. Trough habitats (Fig. 54) showed similar seasonal fluctuation, but mycelium, m/gdws, remained somewhat constant such that no large mycelial biomass accumulated. Sharp declines in biomass, m/gdws, in trough habitats were detected as were fall season buildups and general declines thereafter to freeze up. In trough habitats, more than any other, the variation between fiducial limits at all depths, as defined by standard errors of means, was so great that a m/gdws distinction between profile depths was difficult to acertain. Overlapping fiducial limits were again encountered in polygon top habitats (Fig. 57), making it difficult if not impossible to show distinct differences in m/gdws between depths in the profile. Basin, habitats (Fig. 56) like top habitats, showed relatively low and constant fungal biomass and

Figure 51. Mean meters of fungal mycelium per gram of dry soil for two soil depths from a series of plots comprising five habitats sampled in 1973.

Figure 52. Mean fungal biomass in grams per square meter for a 1 cm wafer at two depths from the five 1973 habitats.

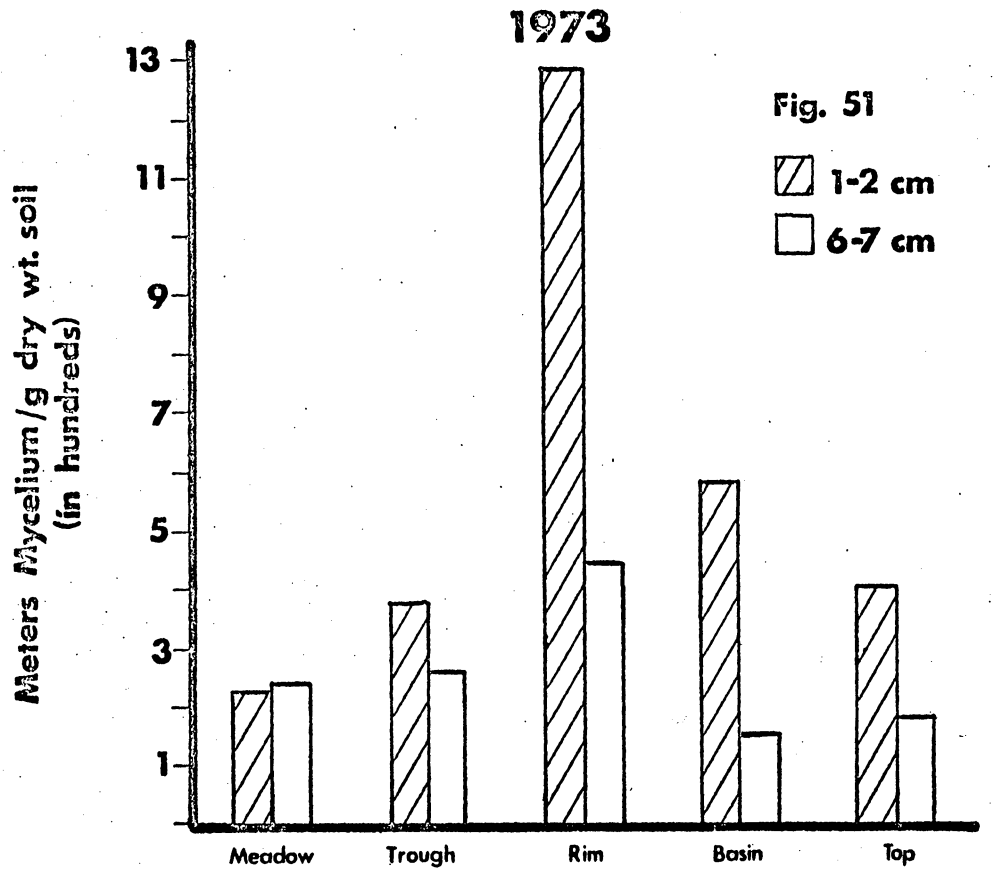

1973
Meters Mycelium/g dry wt. soil (in hundreds)
13
11
9
7
5
3
1
Meadow
Trough
Rim
Basin
Top
1-2 cm
6-7 cm

Fig. 51

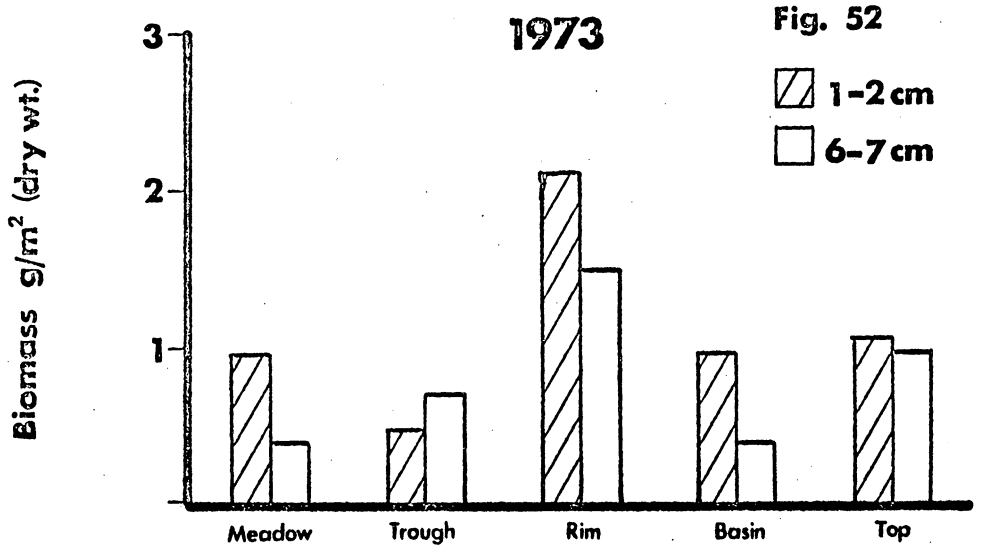

1973
Biomass g/m² (dry wt.)
3
2
1
Meadow
Trough
Rim
Basin
Top
1-2 cm
6-7 cm

Fig. 52

little seasonal fluctuation.

The greatest fungal biomass average of 1093 m/gdws was found in the upper 2 cm in soils of rim habitats during all three (1972-1974) seasons (Table 1B of Appendix 7). Meadow habitats, with 963 m/gdws, had almost twice the fungal mycelium found in soils of trough habitats, with 495 m/gdws, and basin habitats, with 471 m/gdws. Polygon top habitats were lowest with 244 m/gdws. In 1973, meadow habitats were just reversed from the 3 year trend and showed the lowest m/gdws of any habitat (Fig. 51).

Figure 53. Seasonal fluctuation and standard error of means for meters of mycelium per gram dry soil in meadow habitats, 1973.

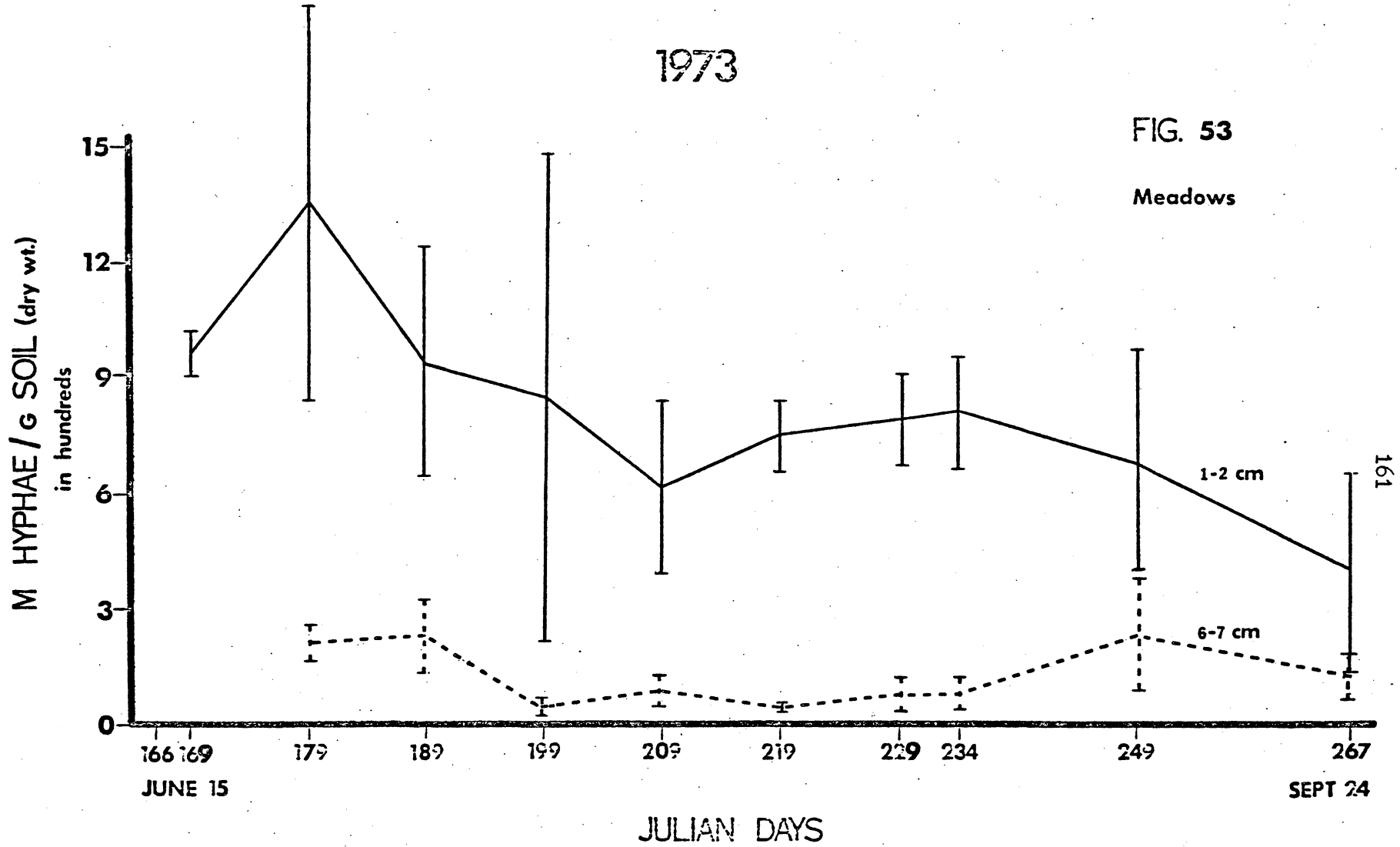

1973
FIG. 53
Meadows
M HYPHAE / G SOIL (dry wt.)
in hundreds
15
12
9
6
3
0
1-2 cm
6-7 cm
166 169
179
189
199
209
219
229 234
249
267
JUNE 15
SEPT 24
JULIAN DAYS
161

Figure 54. Seasonal fluctuation and standard error of means for meters of mycelium per gram dry soil in trough habitats, 1973.

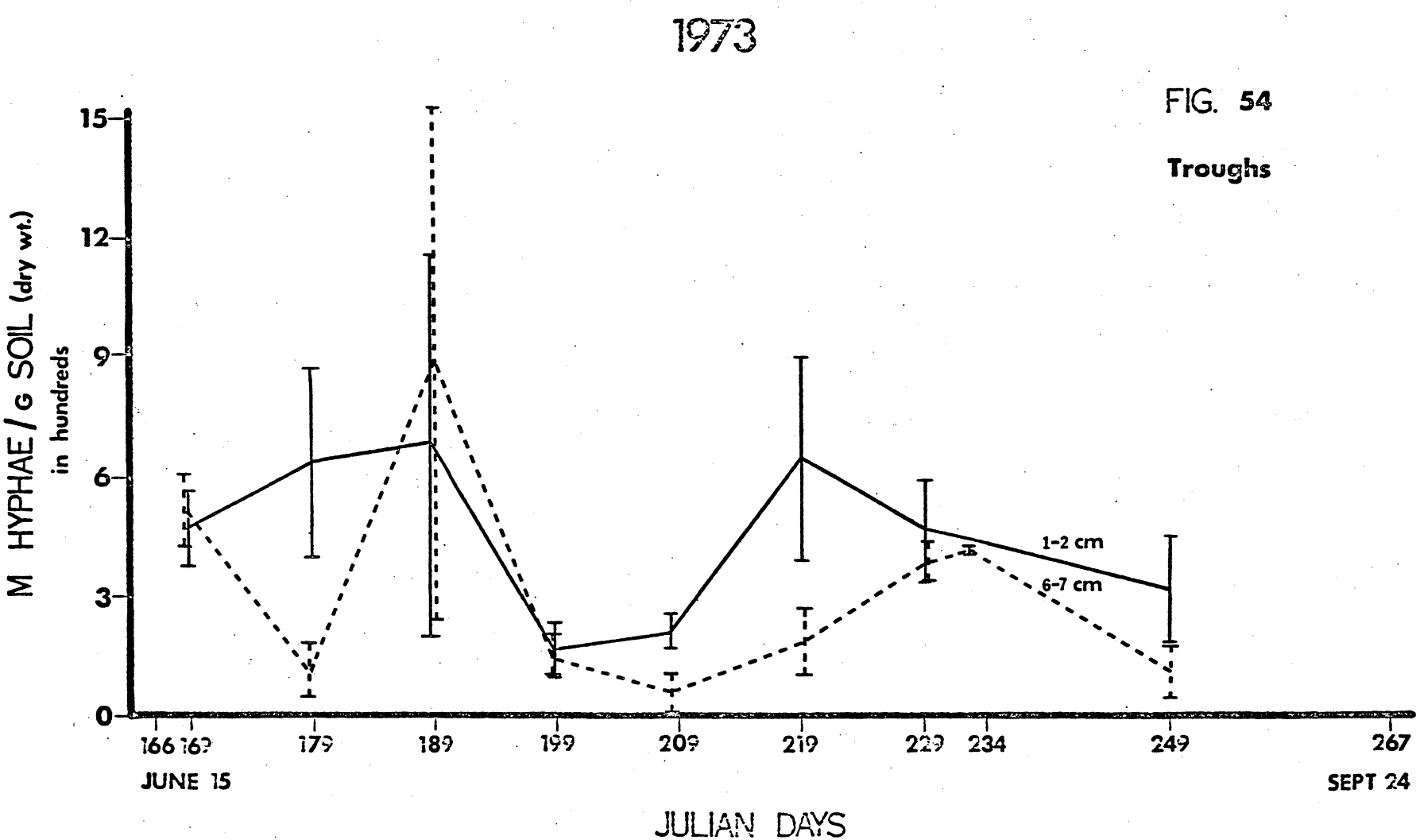

1973
FIG. 54
Troughs
M HYPHAE / G SOIL (dry wt.)
in hundreds
15
12
9
6
3
0
1-2 cm
6-7 cm
166 169
179
189
199
209
219
229 234
249
267
JUNE 15
SEPT 24
JULIAN DAYS

Figure 55. Seasonal fluctuation and standard error of means for meters of mycelium per gram dry soil in rim habitats, 1973.

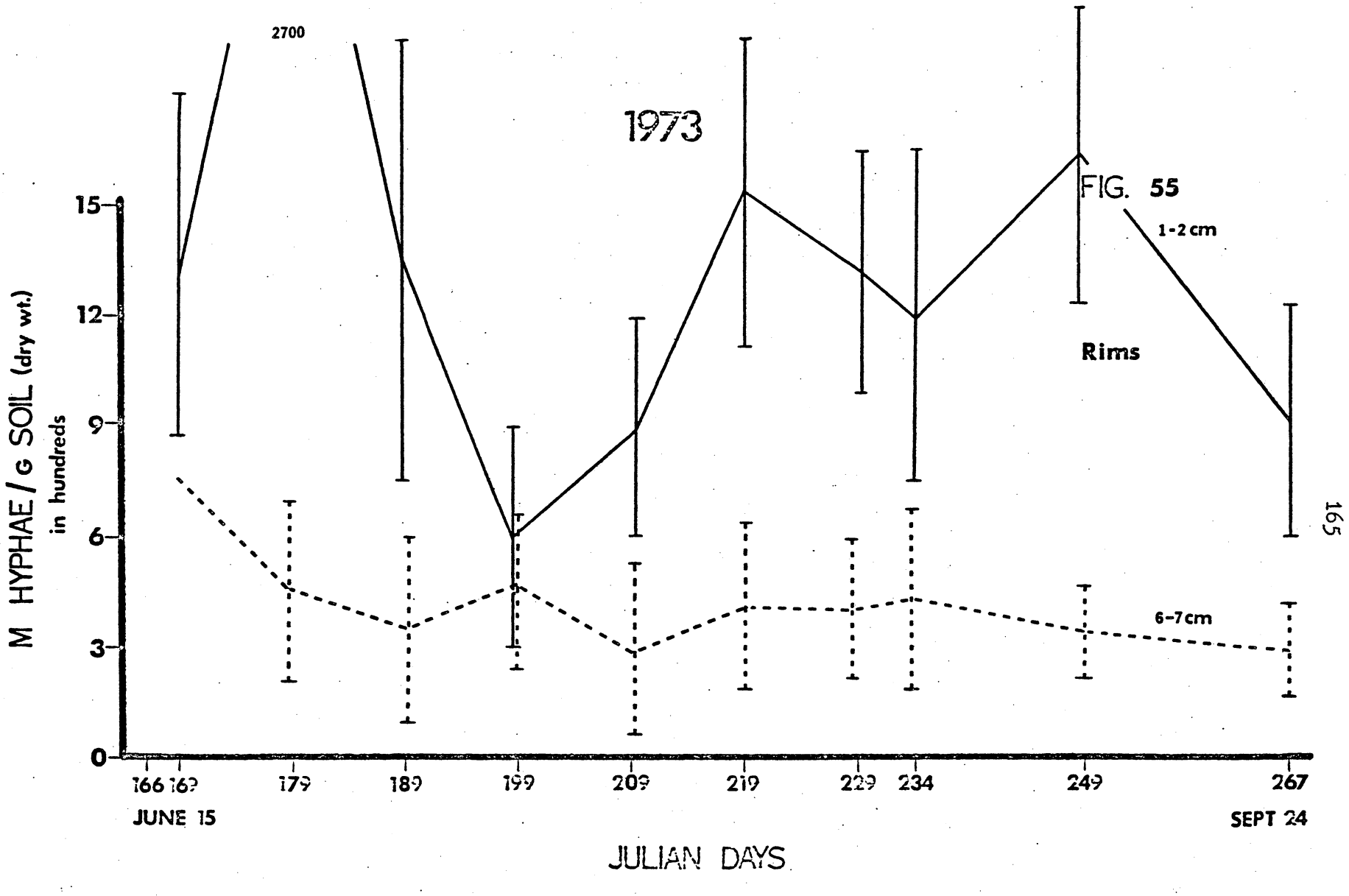

2700
1973
FIG. 55
1-2 cm
Rims
6-7 cm
M HYPHAE / G SOIL (dry wt.)
in hundreds
15
12
9
6
3
0
166 169
179
189
199
209
219
229 234
249
267
JUNE 15
SEPT 24
JULIAN DAYS

Figure 56. Seasonal fluctuation and standard error of means for meters of mycelium per gram dry soil in basin habitats, 1973.

1973

FIG. 56

Basins

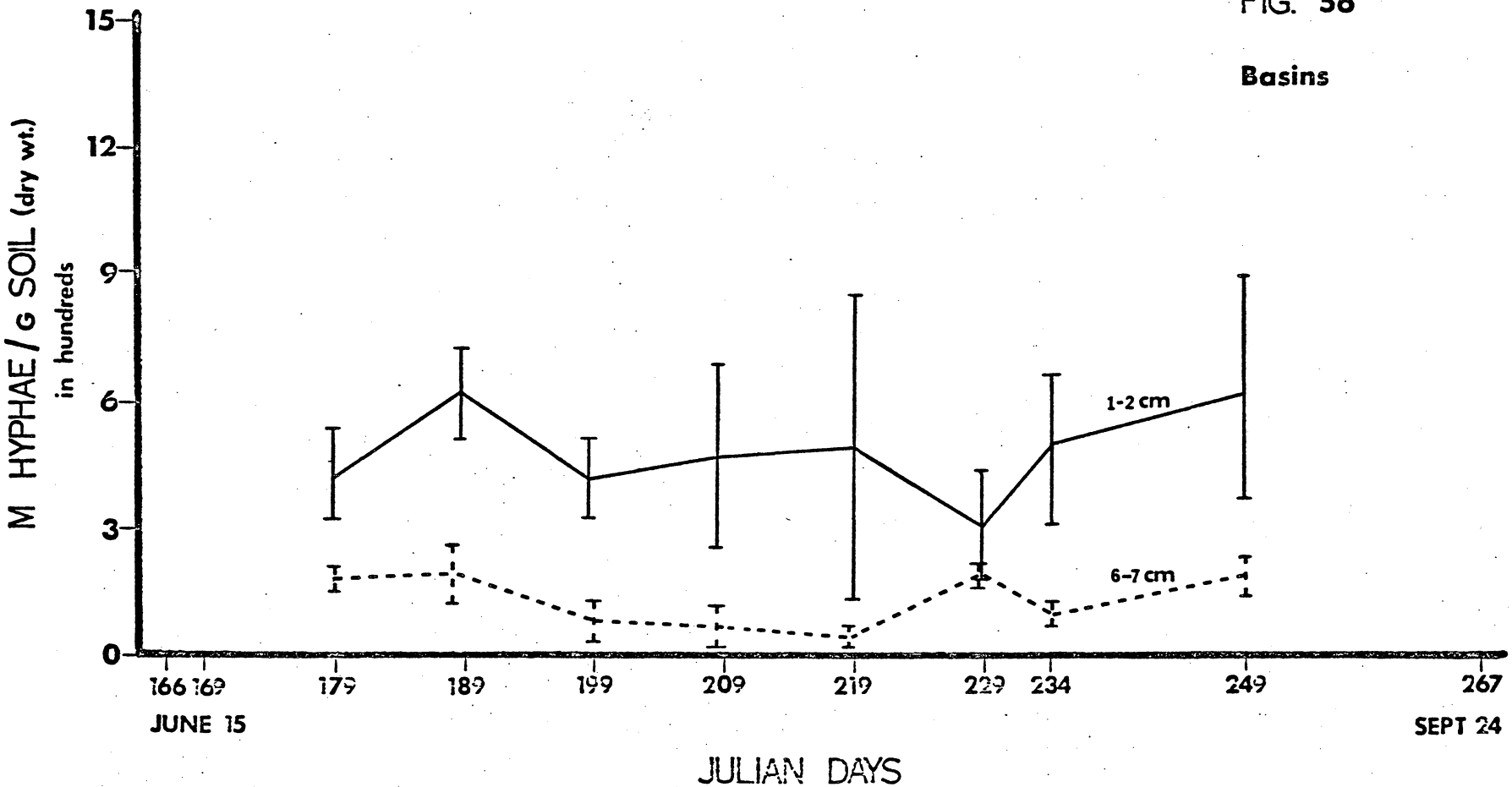
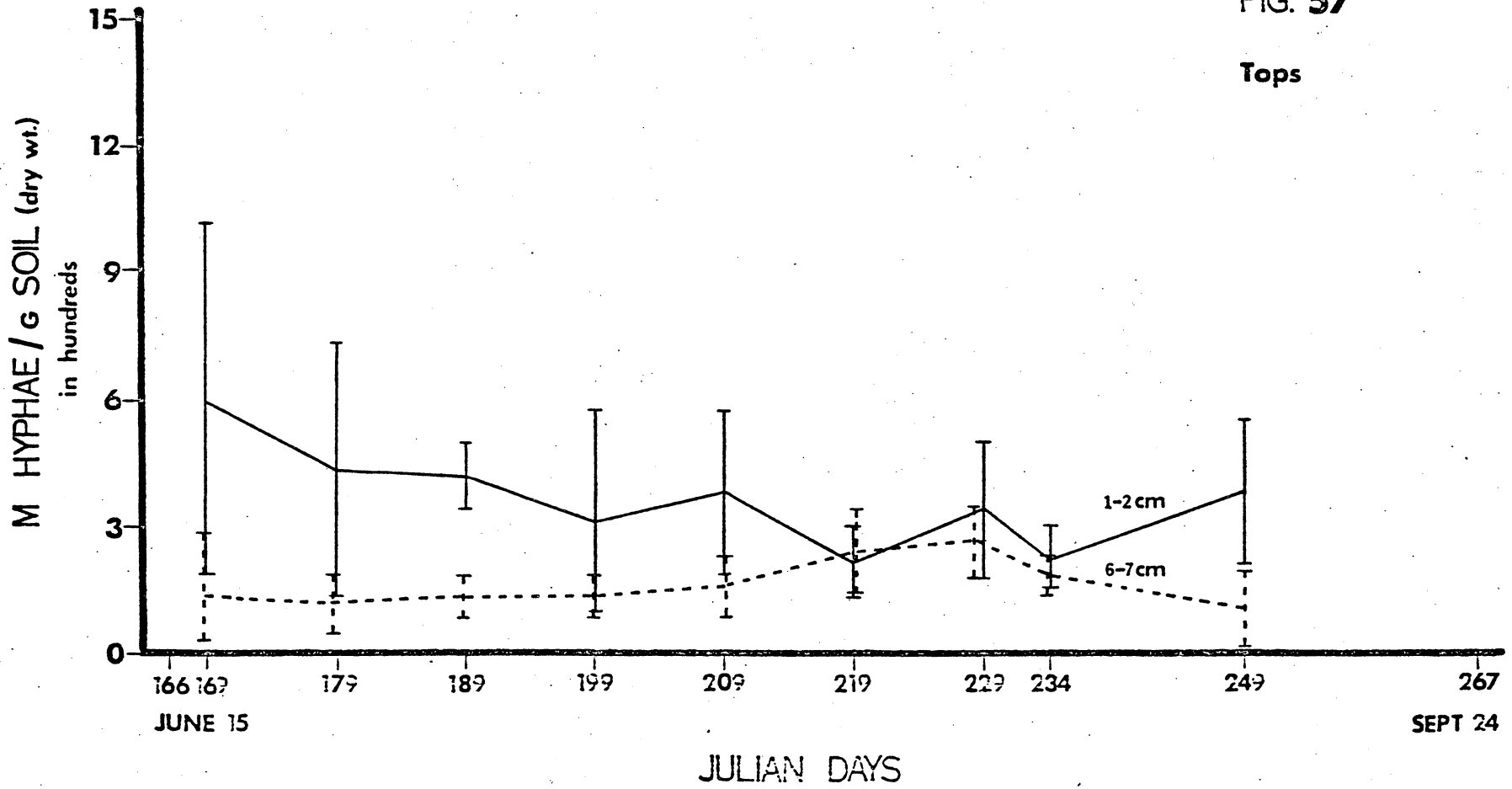


Figure 57. Seasonal fluctuation and standard error of means for meters of mycelium per gram dry soil in top habitats, 1973.

1973

FIG. 57

Tops



IV Mycelial Composition of Peat Soil

No attempt was made to identify the soil fungi isolated. This was done for litter and soils from the Barrow IBP sites by Flanagan and Scarborough (1973). The presence and absence of mycelium with clamp connections was recorded. This allowed for the separation of basidiomycete hyphae from all other hyphal types. Values recorded for clamped hyphae, however, do not necessarily reflect the true or total presence of basidiomycetes in the soils. Cultural studies of Arctic basidiomycetes have shown that average hyphal cell lengths were 58 μm. Many fragments that were observed and measured from soil samples were cells without septa and could have been basidiomycetes. All basidiomycetes do not necessarily have clamps in their vegetative phase. A good example is the genus Russula. Two species are common in Arctic tundra from Barrow to Umiat (Miller et al., 1972). Therefore, one major problem in making % clamped vs unclamped mycelium predictions is certainty in underestimating the actual standing crop of basidiomycete mycelium. As much as 51 % of the mycelia observed from tundra soils of rim habitats, Plot 427, in the vicinity of Barrow, belonged to basidiomycetes (Table 15). Values for basin habitats were approximately 1 %. But the results obtained do indicate at least minimum values for the presence of basidiomycete hyphae in tundra soils.

Flanagan and Scarborough (1974) predicted the percentage of hyphae with clamps in Arctic soils made at 30 %. Burges (1958) claims that low incidences of basidiomycetes, as reported in the literature, were results of cultural artifacts. The data presented here were obtained from direct observations. What was important was not a total clamped

TABLE 13

1973 SOIL DEPTH OF THAW MEANS BY HABITAT[1]

Habitat	Thaw depth (cm)
Meadow	21.2
Trough	24.6
Rim	21.8
Basin	20.7
Top	22.7

[1]On US IBP Tundra Biome Sites, Barrow, Alaska.

TABLE 14

PERCENT CLAMPED AND UNCLAMPED HYPHAE BY HABITAT

Habitat	1972		1973	
	% Unclamped	% Clamped	% Unclamped	% Clamped
Meadow	80.3	19.6	93.4	6.6
Trough	76.0	24.0	92.2	7.8
Rim	72.0	28.0	80.8	19.2
Basin	92.5	7.5	89.0	11.0
Top	82.0	18.0	90.8	9.2
Overall Mean	80.6	19.4	89.2	10.8

TABLE 15

PERCENT UNCLAMPED AND CLAMPED HYPHAE MEANS BY PLOT

Plot	1972		1973	
	% Unclamped	% Clamped	% Unclamped	% Clamped
100	-	-	98	2
101	-	-	95	5
138	0	0	-	-
200	-	-	90.1	9.9
400	71	29	91	9
414	92	8	97	3
415	92	8	94	6
416	75	25	80	20
417	72	28	62	38
418	96	4	94	6
419	82	18	92	8
420	92	8	98	2
421	79	21	96	4
422	83	17	91	9
423	84	16	99	1
424	81	19	83	17
425	77	23	78	22
426	70	30	74	26
427	57	43	49	51
428	93	7	88	12
440	-	-	95	5
441	-	-	97	3
442	-	-	99	1
450	62	38	-	-
1232	-	-	93	7
1233	-	-	89	11

hyphae %, but how % clamped hyphae varied from habitat to habitat. The data in Table 14 show actual observed mean values for clamped and unclamped hyphae percents in each of the five habitat types. Interesting trends become apparent. First, 1972 samples showed 44 % more clamped hyphae overall than were detected in 1973 (Table 14). Recalling that 1973 was a much wetter year than 1972 might suggest that increased soil moisture may have had some influence on reduced percentages of clamped hyphae in 1973. Rim habitats had the greatest hyphal biomass and consistantly showed the highest clamped hyphae percents during 1972 and 1973 (Table 14). Trough habitats, in 1972, and basin habitats, in 1973, the two wettest habitat types, followed rim habitats with the second highest percentages of clamped hyphae. Top habitats had the lowest total biomass and soil moisture percents. Found here too were moderately high basidiomycete assemblages of 0.2 to 18 %. Meadow habitats showed a great deal of variability during 1972 and 1973 with clamped hyphae values ranging from 7-20 %. Wet trough habitats ranged from a low 8 % to a high 24 % from 1972 to 1973. Basin habitats ranged from 8 % to 11 % during the same period. These data suggest that soil moistures were of little significance to clamped versus non clamped hyphal presence. The presence or absence of clamped hyphae may simply be one more indicator of what is beginning to be great inherent variability within and between the habitats as defined earlier by their vascular plant assemblages. It may be that clamped hyphae % are more closely associated with and explained by a particular vascular plant community.

Studies of the fungi were made during the fruiting periods and

it has been shown that mycorrhizae forming basidiomycetes dominated the rim and high center polygon top habitats. The root zones of these mycorrhizal plants, particularly those root zones of three Salix species, appeared very near the surface. Examination of these roots have resulted in the finding of abundant ectomycorrhizal sheaths (Miller et al., 1972). Concomitant with the presence and abundance of basidiocarps and mycorrhizal sheaths the percents of clamped hyphae in the soil were also elevated. Low percentages of clamped hyphae were found in wet soils of polygon trough and basin habitats. But, then fewer species and lower numbers of basidiocarps were also found.

V The Influences of Soil Moisture on Fungal Biomass

Water content of soil was usually expressed gravimetrically as the weight of water per unit weight of dry soil or as the volume of water per unit volume of bulk soil. Gravimetric weights were used in this study and the results are expressed as percents (Table 17a and b). Thus a soil moisture of 450 % was equal to 1 unit weight of soil in 4.5 unit weights of water.

It was difficult to single out influences of soil moisture as they were related to the fluctuations of fungal biomass. Some authors discuss percent of soil saturation while others talk in terms of percent moisture holding capacity. Holding capacity varies with what has been termed, matric suction, which is defined as the potential of a soil substrate to suck up water. Holding capacity, the ability of the substrate to retain water once having sucked it up, has been variously referred to as pF.0, field capacity, normal moisture capacity, field water capacity, moisture equivalent, and moisture holding capacity (Griffin, 1966a). Griffin (1966b) points out to biologists that the Commission of the International Society of Soil Science (Bull. no. 23, 1963) recommended using the phrase 'matric suction' rather than holding capacity or any of its synonyms listed above.

Different soils will maintain different matric suction potentials. This was particularly true for humic soils characteristic of the Barrow sites because of different and high organic matter compositions. In this study, peat soils include histic and pergellic cryaquepts, cryohemists and cryosaprist (Gersper et al., 1974b), and were included together as wet meadow tundra because of their similar organic matter

compositions. They were therefore, assumed to have had similar matric suction potentials. This assumption was made because peat soils from various plots within the U.S. IBP Barrow Sites were similar in total carbon percents and organic matter content. They characteristically differed in the amount of soil water held because of geomorphic and altitudinal differences in relation to the water table. Arctic Brown soils of beach ridge plots 450, 1232 and 1233 were, however, much different than wet meadow tundra soils. Besides being much higher and well drained, they formed perhaps the most distinct habitat type with respect to soil moisture levels. Soil moisture percents there were the lowest found on any habitat. By using soil moisture percents as one criterion then, groups of similar plot types were conveniently divided into the five habitats of meadow, rim, trough, basin and high top.

Griffin (1960, 1963, 1966a, 1966b) and Chen and Griffin (1966a and b) suggested from their observations that temperature and moisture (relative humidity and matric suction) interact to control the activity and survival of fungi. Visser and Parkinson (pers. comm.) have demonstrated statistically that soil moisture had highest correlation coefficients to total fungal biomass, .5231, to live biomass, .5644, and to respiration at 10, 5 and 0 C, .8522, of any other single variable. Microbes, according to Benoit (pers. comm.), respire readily at the above temperatures in Barrow soils.

In this study, comparisons of total fungal biomass were made to moisture contents of the soil. Moistures were expressed in dry weight percents.[1] Variations showed overall seasonal averages of 274 % in

[1]Soil moisture (Dry Wt. %) $= \frac{\text{known soil vol. wet wt. - dry wt.}}{\text{dry wt.}} \times 100$

1972, 335 % in 1973 and 223 % in 1974. The wetter 1973 field season was due in part to the release of moisture from a deeper thaw of the active layer and from greater precipitation. In 1972, 3 cm of precipitation were recorded from June 1 to September 30. In 1973, 9 cm fell during the same period.

Fluctuation of soil moistures through any one season showed patterns very similar to the fluctuation of fungal biomass. That is, soil moisture exhibited early season vernal highs due to snow melt. These highs were 544 % in 1972 and 419 % in 1973 (Table 5 and 6, Appendix 3 and Table 4D, Appendix 7). Sharp declines followed to mid season lows of 209 % in 1972 and 303 % in 1973. Thereafter, increases in soil moisture percents of 263 % and 380 % were measured up to the period of fungus fruiting. Continued increases followed. Toward the season's end moisture levels of 302 % and 357 % for 1972 and 1973 were measured. From the data in Table 16, as expressed in Fig. 58, an optimum soil moisture range for fungal biomass was approximately 400-450 % for m/gdws and 200-300 % for g/m^2 biomass.

Early, mid and late season soil profiles of soil moisture showed continued decline to the 7 cm depth in 1973. The only exception to this decline with depth was an increase from 181 % to 258 % on day 209 and from 173 % to 243 % on day 234 at the 7 cm depth (Table 17b).

Similarities and differences in soil moistures between plots provided criteria for separating them into the five habitats. Along the moisture gradient trough habitats consistantly showed the highest seasonal soil moistures with values ranging from 426 % in 1972 to 481 % in 1973. The only exception was in 1974 when basin habitats, with

TABLE 16

1973 METERS MYCELIUM/gdws, BIOMASS AND SOIL BULK DENSITY (g/cc) BY SOIL MOISTURE CLASSES

Moisture	Meters	Biomass	Bulk density
0-99	189.4	1.045	.817
100-199	343.0	1.104	.469
200-299	595.6	1.233	.289
300-399	736.7	1.129	.227
400-499	983.8	1.141	.160
500-599	820.7	.727	.155
600-699	562.6	.540	.110
700-799	991.5	.710	.098
800-899	504.6	.370	.093
900- +	283.7	.360	.116

Figure 58. Mean belowground fungal mycelium, meters and biomass, on all plots as related to soil bulk density and soil moisture % (dry wt.).

1973
Fig. 58
Soil Bulk Density (g/cc)
1.5
1.0
.5
0
Meters Mycelium/g dry wt. soil
(in hundreds)
10
8
6
4
2
0
meters
biomass
b.d.
0 1 2 3 4 5 6 7 8 9 10
Soil Moisture (% dry wt.)
(in hundreds)
1.5
1.0
.5
0
Biomass g/m² (dry wt.)

TABLE 17a

1973 SOIL PROFILE MOISTURE MEANS FOR A 1CM WAFER $1m^2$ TO A 7CM DEPTH BY DEPTH-DAY[1]

Profile depths[2] in cm	Overall means	Soil moisture (wet wt. %)		
		June 28 JD 179	July 28 JD 209	August 22 JD 234
1	.806	.830	.801	.787
2	.754	.800	.779	.749
3	.729	.774	.713	.700
4	.691	.749	.662	.661
5	.649	.709	.626	.615
6	.593	.668	.558	.558
7	.581	.626	.521	.533

TABLE 17b

Profile depths in cm	Overall means	Soil moisture (dry wt. %)		
		June 28 JD 179	July 28 JD 209	August 22 JD 234
1	516.5	623.7	477.7	448.2
2	435.6	555.8	420.5	396.7
3	392.2	472.2	357.6	346.9
4	340.8	412.9	307.2	302.2
5	277.9	353.8	247.3	236.0
6	209.6	278.1	180.5	173.2
7	198.4	214.9	257.7	243.3

[1]Depth-day means include all plots (24) on the US IBP TB Sites moisture gradient, Barrow, Alaska.

[2]1=0-1cm, 2=1-2cm, etc.

314 %, and meadow habitats, with 271 %, exceeded the seasonal mean moisture, 264 %, of trough habitats (Table 4A, Appendix 7).

Meadow habitats had moisture levels exceeded only by troughs (Table 4B, Appendix 7). Basin habitats, 283-375 %, were wetter than rim habitats, whose moisture percents ranged from 167-262 %. Polygon high center top habitats were consistantly drier, 50-128 %, than all other habitats. Within the soil profile, soil moistures at the 1-2 cm depth in all 5 habitats were 2 to 3 times greater than those moisture levels detected at 6-7 cm (Table 4C, E and F, Appendix 7). The only exception to this was found in trough habitats where moisture levels at 6-7 cm were slightly higher than those at 1-2 cm. Soil moisture percents were important because they were limiting factors which incluenced the belowground fungal biomass levels.

Interpretations of the influence of soil moisture on fungal biomass were difficult to detect because the influences of soil bulk density can not be easily isolated. Soil moisture percents were very much a function of soil bulk density as both were determined gravimetrically. As soil moistures increased, soil bulk densities decreased, and more sharply at first (Fig. 58). It was difficult to tell whether fungal mycelium, m/gdws, responded more directly to soil moisture or to soil bulk density. Logically, both may be and probably were limiting to the fungi. Too much moisture will limit growth of aerobic hyphae. Too little moisture is also limiting in that soil becomes more compacted. Too much soil per unit volume will physically restrict hyphal growth particularly if the soil particles are clay-like such as the mineral layers below the surface peats on the Barrow sites.

Soil bulk densities reflect physical substrate quality then, with respect to aeration, absorption and confinement. They also reflect chemical substrate quality in the organic matter percent available for fungal colonization. It may be seen then that fungi do respond to bulk density as well as to total soil moisture.

In an attempt to remove the possible effects of soil bulk density from the influences of soil moisture on fungal mycelium, m/gdws, moisture and mycelial biomass were stratified by seven bulk density classes (Table 18). Mycelium, m/gdws, was then plotted against soil moisture to detect distribution and the relationships between fungal mycelium and percent soil moisture. Univariate statistical analyses (Table 18) showed that stratifying belowground fungal mycelium, m/gdws, and soil moisture classes by soil bulk density excluded most if not all effects that soil bulk density might have had on the biomass. With decreased moisture there was a concomitant decrease in mycelium and plotted moisture vs mycelium data showed no overlapping of bulk density classes, with one exception. When soil bulk density was high, .7-.9 g/cc, fungal mycelium vs moisture curves overlapped. This indicated that at soil moisture levels between 70-80 % (dry wt.) it becomes almost impossible to separate the effects of soil moisture and soil bulk density on the standing crop of belowground fungal mycelium.

In order to test what was discovered, soil bulk density and fungal mycelium were stratified by soil moisture classes to see if indeed bulk density and moisture were independant of each other. This was not the case as is shown in Table 20, but the influences of bulk density on biomass will be discussed in the next section. For clarification, soil bulk density influences can not be separated from those

of soil moisture. However, the influences of soil moisture on fungal mycelium are separable from those influences of soil bulk density.

From Fig. 58 and 59 it becomes evident that soil moisture and bulk density were highly interactive. As moisture decreased, bulk density increased. It would also appear from the data in Fig. 60 that fungal biomass, g/m^2, might be more highly correlated with soil bulk density than was mycelium, m/gdws. Biomass was, by virtue of using the soil bulk densities in the calculation, influenced by soil bulk density because it was a reflection of the physical state of the substrate. With increased soil moisture there was less available substrate, more space that was filled with water and a decrease in soil bulk density (Fig. 59). Lengths of mycelium, m/gdws, decreased and so did the amplitudes of difference as expressed between fiducial limits on standard errors of the means. Even then, the presence of fungal mycelium was best explained by soil moisture percents and not soil bulk densities.

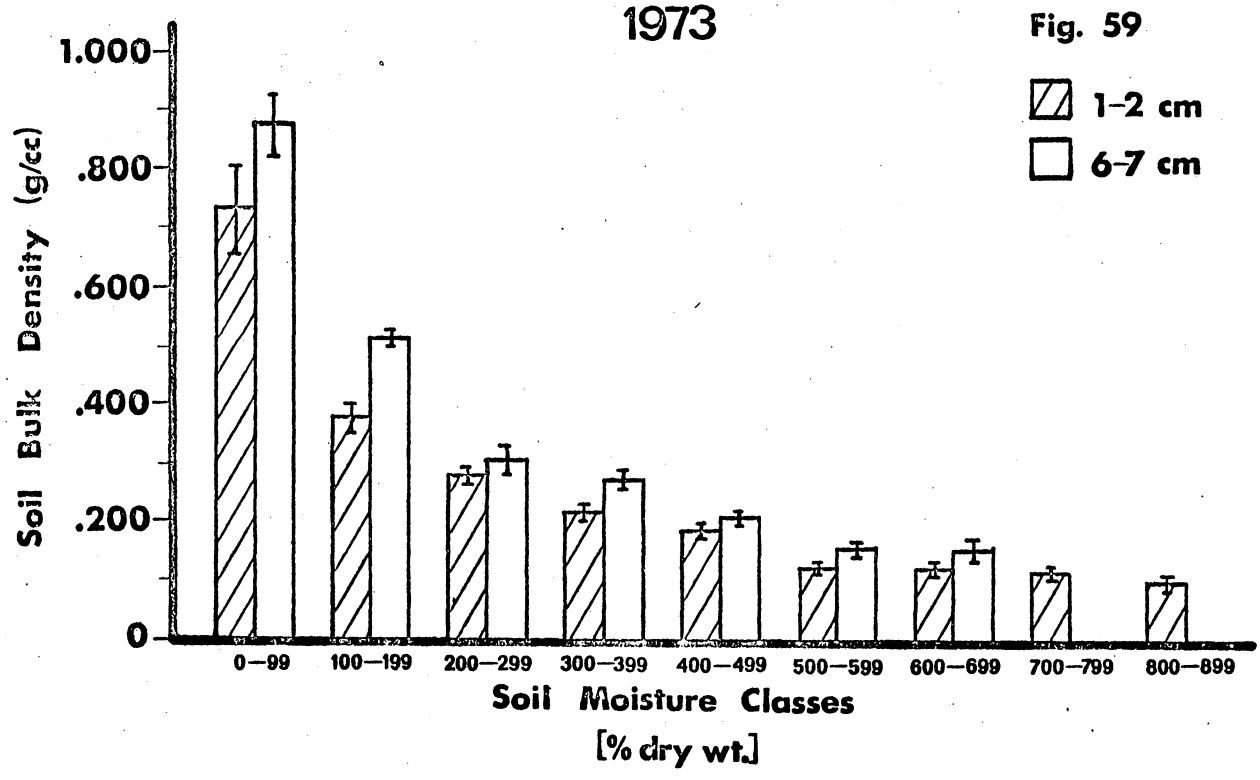
TABLE 18

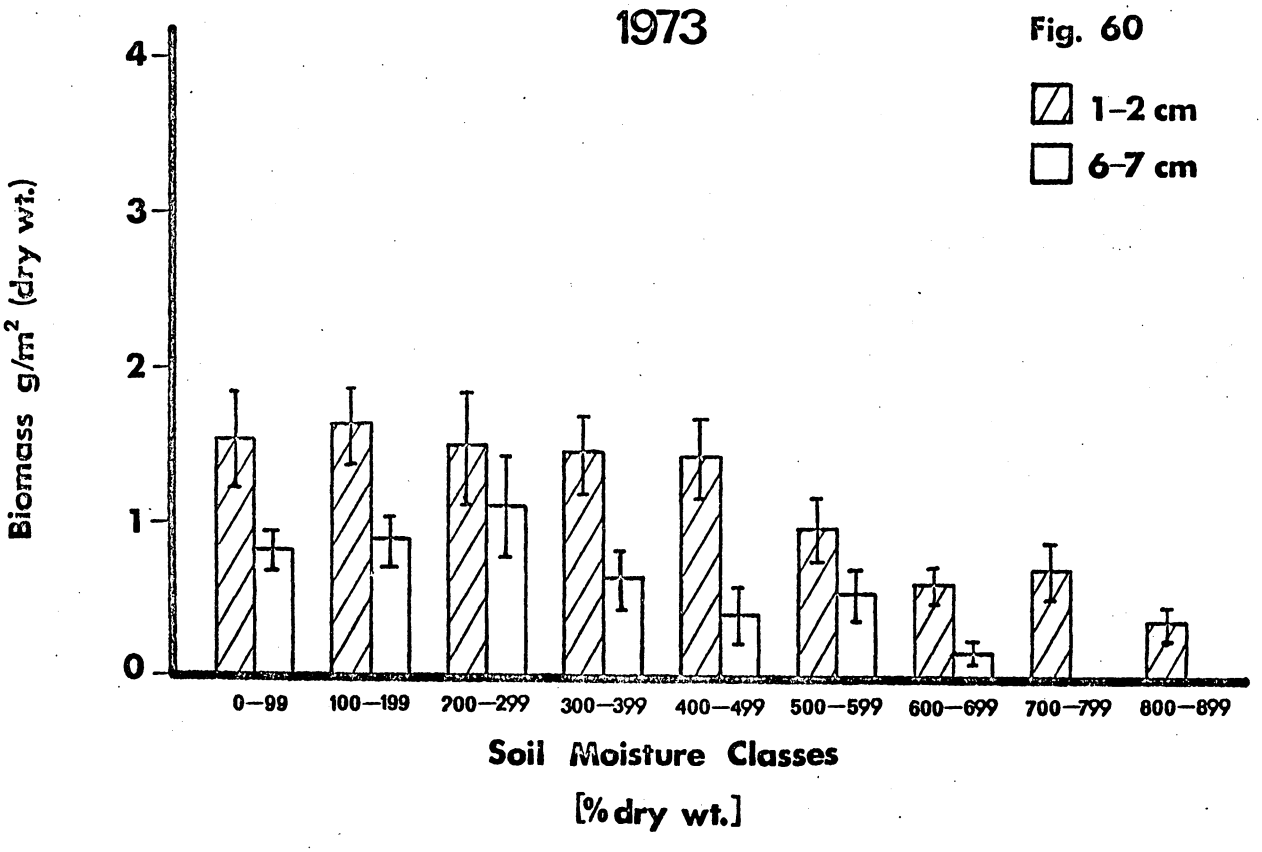
1973 Soil Moisture (dry wt. %) and Mycelium (m/gdws) Means and Variation by Bulk Density Classes

Bulk Density class	N	Soil moisture (dry wt.%) Mean	CV %	m Mycelium/gdws Mean	CV %
1	297	566 ± 186	33	869 ± 1116	128
2	246	286 ± 86	30	606 ± 734	121
3	95	129 ± 44	34	265 ± 276	104
4	59	91 ± 22	24	231 ± 278	121
5	37	61 ± 14	23	129 ± 184	143
6	28	37 ± 18	47	130 ± 153	118
7	14	19 ± 11	59	106 ± 147	138

Figure 59. Mean soil bulk density from two profile depths as related to mean soil moisture % classes during 1973 at Barrow, Alaska.

Figure 60. The relationship of mean fungal biomass, g/m^2, to mean soil moisture % classes for two soil profile depths during 1973 at Barrow, Alaska.


1973
Fig. 59
1-2 cm
6-7 cm
Soil Bulk Density (g/cc)
1.000
.800
.600
.400
.200
0
0—99
100—199
200—299
300—399
400—499
500—599
600—699
700—799
800—899
Soil Moisture Classes
[% dry wt.]


1973
Fig. 60
1-2 cm
6-7 cm
Biomass g/m² (dry wt.)
4
3
2
1
0
0—99
100—199
200—299
300—399
400—499
500—599
600—699
700—799
800—899
Soil Moisture Classes
[% dry wt.]

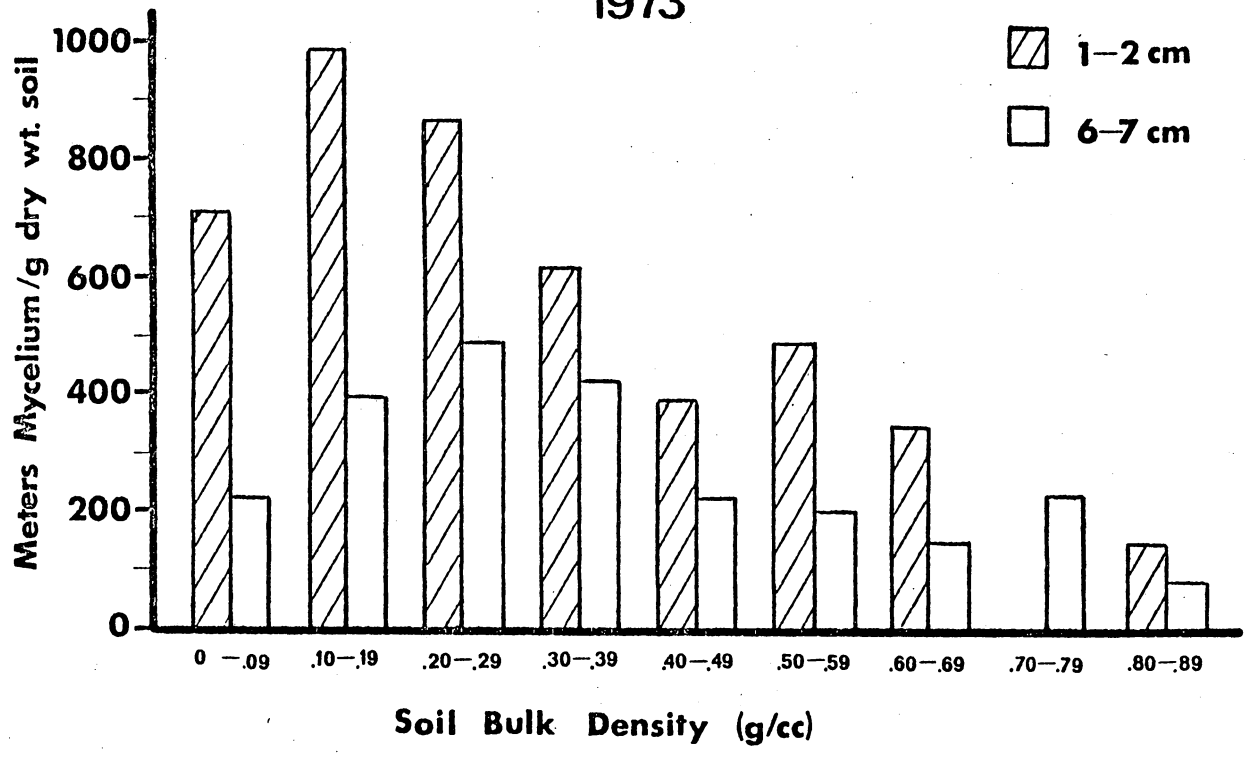
VI The Influences of Soil Bulk Density on Fungal Biomass

Bulk densities of tundra peat soils were determined gravimetrically on a dry weight basis from a 5.08 cm diameter soil wafer. It was important to use soil bulk densities to express belowground fungal biomass, not in m/gdws, but in g/m^2 because of volume changes in the substrate. If the unit volume of soil fluctuated, so would the fungal biomass when expressed in terms of a volume of that soil. The expansion and contraction of peat was primarily due to thermal and hydraulic conductivities. This "rise and fall" of tundra, even though slight, was actually measured by Flint (pers. comm.). Soil Bulk densities were also greatly influenced by the hydrolgic freeze thaw cycle. The highly organic soils were strongly influenced and manipulated by increased and decreased soil moisture, to which densities were closely associated. With increased soil bulk densities, there were concomitant decreases in soil moisture percents (Table 21, Fig. 63). Univariate statistical analyses of data show that the effects of soil bulk density were inseparable from the influences of soil moisture. It has also been shown that influences of soil moisture were independent of and separable from soil bulk density, at least when soil bulk densities were less than .7 to .9 g/cc.

Throughout the 1973 field season, average soil bulk densities changed from .41 g/cc early in the season to .24 g/cc at mid season and averaged .36 g/cc at season's end. Average soil densities showed vernal highs of .41 g/cc followed by early season lows, .29 g/cc, and general increases throughout the season to the seasonal high of

Figure 61. Mean meters of mycelium per gram of dry soil for 1973 at two profile depths as grouped by soil bulk density classes.

Figure 62. Mean grams of mycelium, dry wt., per square meter at two depths as grouped by soil bulk density classes during 1973.


1973
Fig. 61
1–2 cm
6–7 cm
Meters Mycelium/g dry wt. soil
1000
800
600
400
200
0
0 –.09
.10–.19
.20–.29
.30–.39
.40–.49
.50–.59
.60–.69
.70–.79
.80–.89
Soil Bulk Density (g/cc)

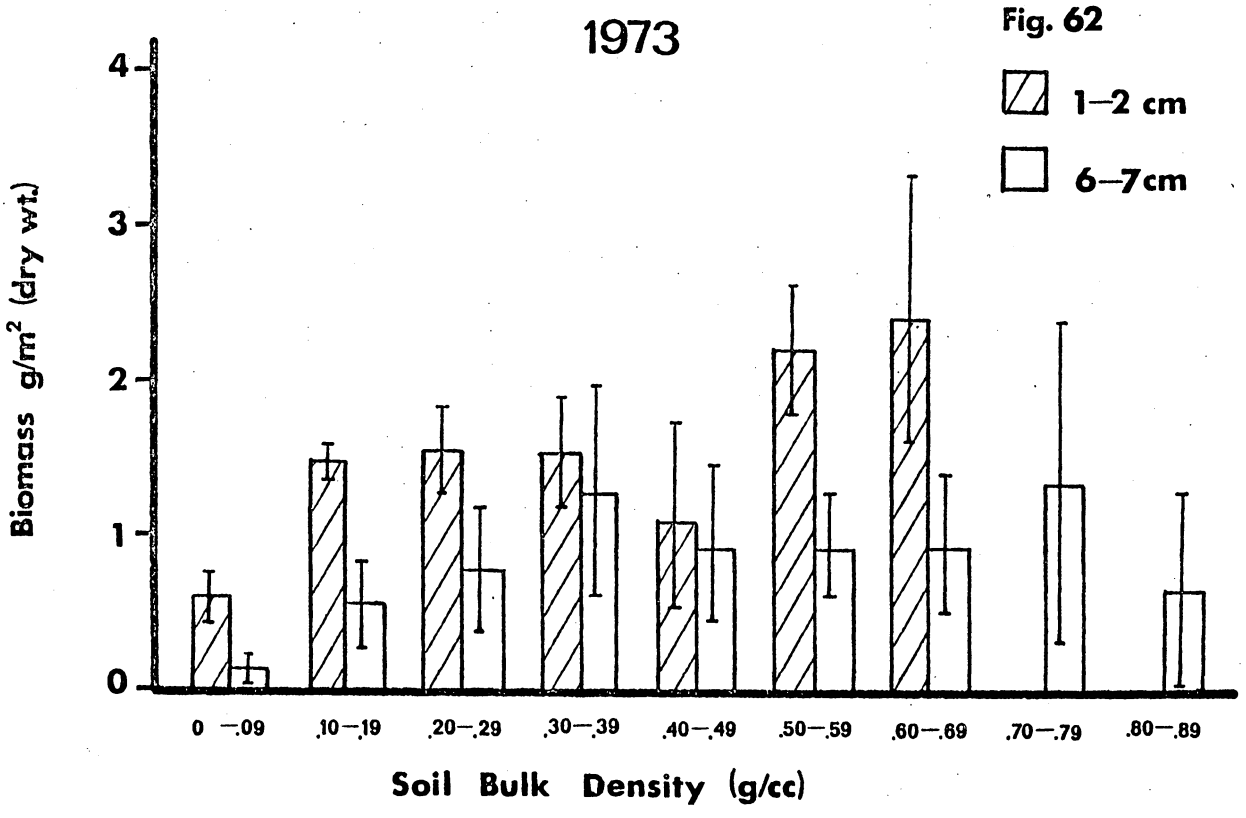
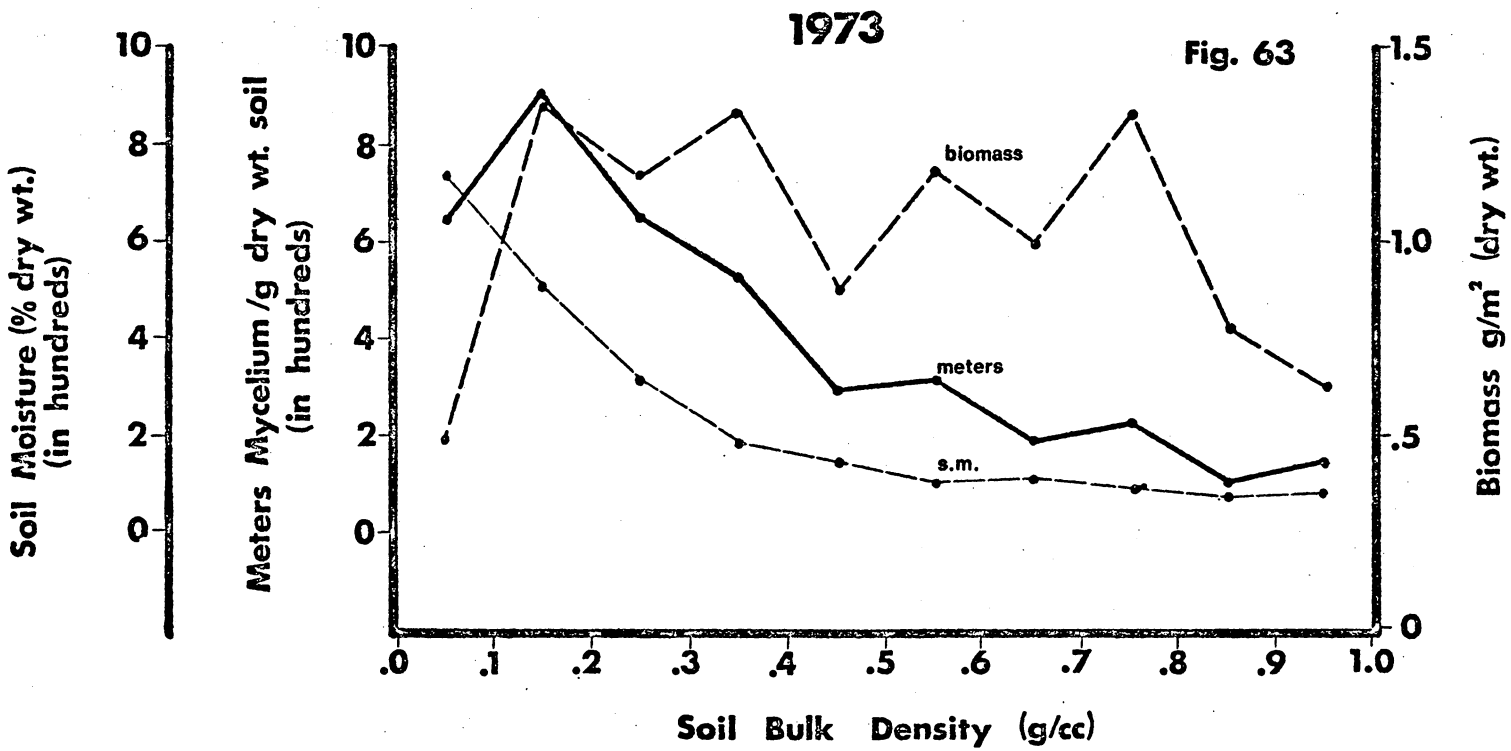

1973
Fig. 62
1–2 cm
6–7cm
Biomass g/m² (dry wt.)
4
3
2
1
0
0 –.09
.10–.19
.20–.29
.30–.39
.40–.49
.50–.59
.60–.69
.70–.79
.80–.89
Soil Bulk Density (g/cc)

TABLE 21

1973 METERS OF MYCELIUM/gdws, BIOMASS (g/m^2) and SOIL MOISTURE (DRY WT. %) BY SOIL BULK DENSITY CLASSES

Soil Bulk density classes	Meters (m/gdws)	Biomass (g/m^2)	Moisture (dry wt.)
0-.099	639	.472	737.7
.1-.199	904	1.352	498.9
.2-.299	641	1.167	306.8
.3-.399	528	1.331	174.4
.4-.499	275	.876	152.9
.5-.599	309	1.176	100.9
.6-.699	187	.986	103.2
.7-.799	238	1.320	96.2
.8-.899	95	.763	66.8
.9- +	142	.674	69.3

Figure 63. Mean soil moisture and soil fungi in meters per gram dry soil and grams per square meter to 1 cm as grouped by soil bulk density classes for the 0-7 cm soil profile during 1973.


1973
Fig. 63
Soil Moisture (% dry wt.) (in hundreds)
Meters Mycelium/g dry wt. soil (in hundreds)
Biomass g/m² (dry wt.)
biomass
meters
s.m.
Soil Bulk Density (g/cc)
0
2
4
6
8
10
.5
1.0
1.5
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

.43 g/cc in mid September (Table 7, Appendix 3). This pattern of fluctuation did not synchronize with either seasonal patterns of fungal biomass or with soil moisture percents. Within the 1973 soil profile (Table 19), average soil bulk densities at the surface were .17 g/cc. They increased almost linearly to .51 g/cc at the 7 cm depth. Each plot, within its habitat along the moisture gradient, had its own characteristic bulk density fluctuations.

Within the five habitats during 1973, soil bulk densities of .61 g/cc were greatest in Arctic Brown soils of high centered polygon top habitats. Rim habitats averaged .43 g/cc, and were followed by troughs at .26 g/cc, and meadows at .23 g/cc. Low center polygon basin habitats had the lowest soil bulk densities of .22 g/cc (Table 3B, Appendix 7). In every instance, within the soils of these habitats, appreciable increases in soil bulk density were detected with increased depth. Means ranged from .13 g/cc at 1-2 cm in trough soils to 1.00 g/cc at 6-7 cm in soils of top habitats.

The relationship of soil bulk density to soil moisture was explored (Fig. 63) because of their patterns of fluctuation throughout a season and with depth in the soil profile within the five habitats. As was discussed earlier in relation to soil moisture, I also wanted to determine whether or not soil bulk density influenced fungal biomass independent of soil moisture. Univariate statistical analysis showed, unlike the influences of soil moisture, that soil bulk density was not separable from the influences of soil moisture by stratifying m/gdws fungal biomass and soil bulk density into soil moisture classes (Table 20). Plotting the m/gdws data from Table 20 showed much overlap.

TABLE 19

1973 SOIL PROFILE BULK DENSITY MEANS IN A 1CM WAFER 1m ^{2} TO A 7CM DEPTH BY DEPTH-DAY ON THREE SAMPLE DAYS

Prifile depths[2] in cm	Overall means	Bulk density		
		June 28 (JD 179)	July 28 (JD 209)	August 22 (JD 234)
1	.172	.146	.159	.211
2	.236	.209	.202	.277
3	.301	.244	.291	.367
4	.360	.280	.382	.418
5	.429	.337	.449	.498
6	.510	.379	.562	.583
7	.508	.460	.624	.621

[1]Depth-day means include all plots (24) on the US IBP TB Site moisture gradient, Barrow, Alaska.

[2]1=0-1cm, 2=1-2cm, etc.

TABLE 20

Stratification of Fungal Biomass and Moisture into Bulk Density Classes

Soil Moisture class	N	Soil Bulk Density (g/cc)		m Mycelium/gdws	
		Mean	CV %	Mean	CV %
1	148	.84 ± .28	33	190 ± 253	133
2	127	.47 ± .12	25	320 ± 388	121
3	105	.28 ± .05	18	580 ± 772	133
4	130	.22 ± .04	18	777 ± 892	115
5	110	.17 ± .03	18	948 ± 1062	112
6	42	.15 ± .02	17	899 ± 1251	139
7	50	.12 ± .02	17	700 ± 1083	155
8	26	.10 ± .02	17	1082 ± 1555	144
9	24	.10 ± .02	18	468 ± 452	97
10	14	.08 ± .01	14	612 ± 726	119

With a decrease in bulk density, as defined by the soil moisture class for a clearly stratified sample, the m/gdws should have showed a gradual but continued increase from 190 to 1082 m/gdws. This was not the case. Data graphed (Fig. 61) showed an apparent optimum soil bulk density of .1 to .2 g/cc at 1-2 cm and .2 to .3 g/cc at 6-7 cm depths in relation to maximum m/gdws fungal biomass. When considering fungal biomass, g/m^2, this bulk density optimum shifted (Fig. 62) to .6 to .7 g/cc at 1-2 cm and .3 to .4 g/cc at 6-7 cm depths. Because fungal biomass was expressed in terms of g soil/cc, there should be a higher corelation of fungal biomass weight to soil bulk density than fungal biomass lengths to bulk density. The range of difference within the standard error of means as defined by fiducial limits, showed increased variation with increased soil bulk density at both the 1-2 cm and 6-7 cm depths (Fig. 62). If the relationship of soil bulk density to fungal biomass was highly correlated, one would expect to find less variance rather than the observed increased variance in the fungal biomass with increasing soil bulk densities. It must be said that fungal biomass was influenced by soil bulk density. Changes in the physical properties of the soil resulted in changes of fungal biomass. Fungal biomass was, however, much less dependant on soil bulk density than it was on soil moisture percents as shown by stratification of fungal biomass of both soil bulk density (Fig. 62) and soil moisture dry weight percents (Fig. 60).

VII The Influences of Soil Temperature on Fungal Biomass

My initial hypothesis was that low seasonal mean temperatures supressed hyphal growth, respiration rates and therefore growth rates and turnover. Aside from generally reducing the activity, temperature seemed to be of little significance to tundra soil fungi.

Examining the Barrow Site 4 temperature data of MacLean, Goodwin and Outcalt (1974) for rim, basin and trough habitats and using both parametric and nonparametric statistics, the influences of temperature on fungal biomass and mycelial growth were explained. Extrapolation of MacLean et al. (1974) data was necessary to correlate temperature at the 7 cm depth. Ten day running means (Table 22 and 23) were calculated. The ten day mean temperatures for the 2 cm depth were plotted (Fig. 64) and used for regressions of temperature on fungal growth. The results of these tests, when using parametric regressions of temperature on biomass growth rates, showed no correlation. The hypothesis that temperature was significant in altering the standing crop of fungi would then be rejected. However, ten day temperature means were then grouped into four temperature classes of 4 C, 4-5 C, 5-6 C and 6+ C and the probabilities of positive fungal growth were determined where

$$r = \frac{\ln (B_t/B_{t-1})}{t} = \text{growth rate.}$$

The normalized cumulative distribution of fungal growth, as stratified by four 10 day mean temperature classes, was plotted (Fig. 65). The probability of positive fungal growth ranged from a low, P = .098, in the 6+ C temperature class, to a high, P = .693,

TABLE 22

1972 MEAN SOIL TEMPERATURE[1]

Date		Rim		Basin		Trough	
		2	7[2]	2	7	2	7
Jn	23-30	4.5	2.6	5.1	3.3	5.1	2.9
Jl	1-14	8.5	6.3	8.3	5.9	7.9	5.1
Jl	15-28	7.1	6.2	6.8	5.3	6.4	4.7
Jl-Aug	29-12	8.1	7.1	7.5	5.9	7.2	5.5
Aug	13-18	6.2	5.4	5.8	4.6	5.6	4.4

[1]Data of MacLean et al. (1974).

[2]Depth 7 temperature extrapolations.

TABLE 23

1973 MEAN SOIL TEMPERATURE

Date		Rim		Basin		Trough	
		2	7	2	7	2	7
Jn	11-20	2.3	-.5	3.2	-.7	1.5	-1.1
Jn	21-30	2.2	.4	3.8	.9	2.7	.3
Jl	1-10	4.3	2.7	4.8	2.5	4.7	2.6
Jl	11-20	3.8	2.6	3.8	2.2	3.8	2.2
Jl	21-30	6.2	4.4	5.5	4.1	5.1	3.4
Jl-Aug	31-9	5.2	4.5	5.2	3.7	5.2	4.2
Aug	10-19	4.3	3.5	4.4	3.2	4.6	3.6
Aug	20-29	4.6	3.8	5.2	3.9	4.7	3.7

Figure 64. Ten day running mean temperatures (MacLean et al., 1974) in degrees centigrade for rim, basin and trough habitats during the 1973 season.

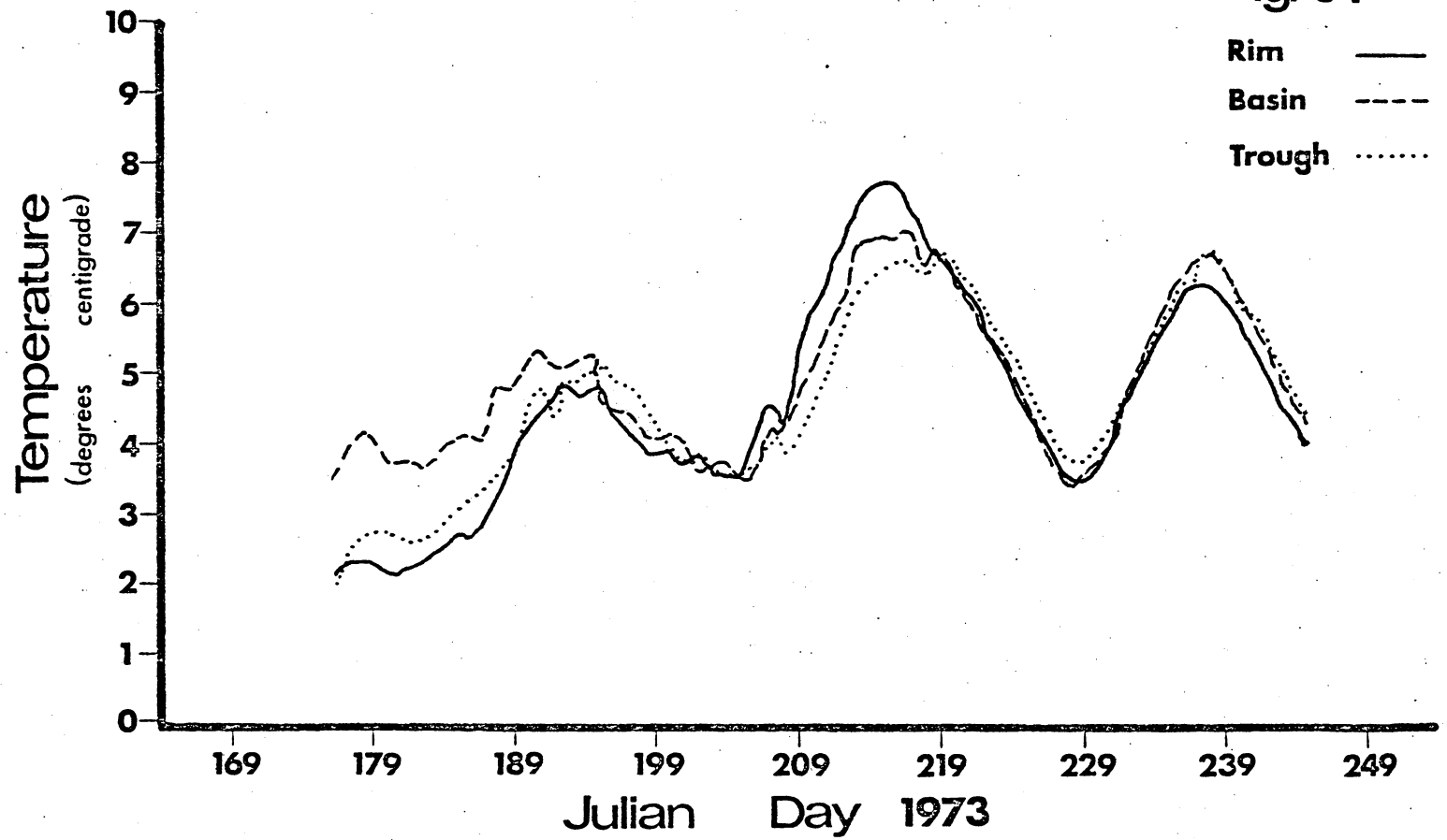


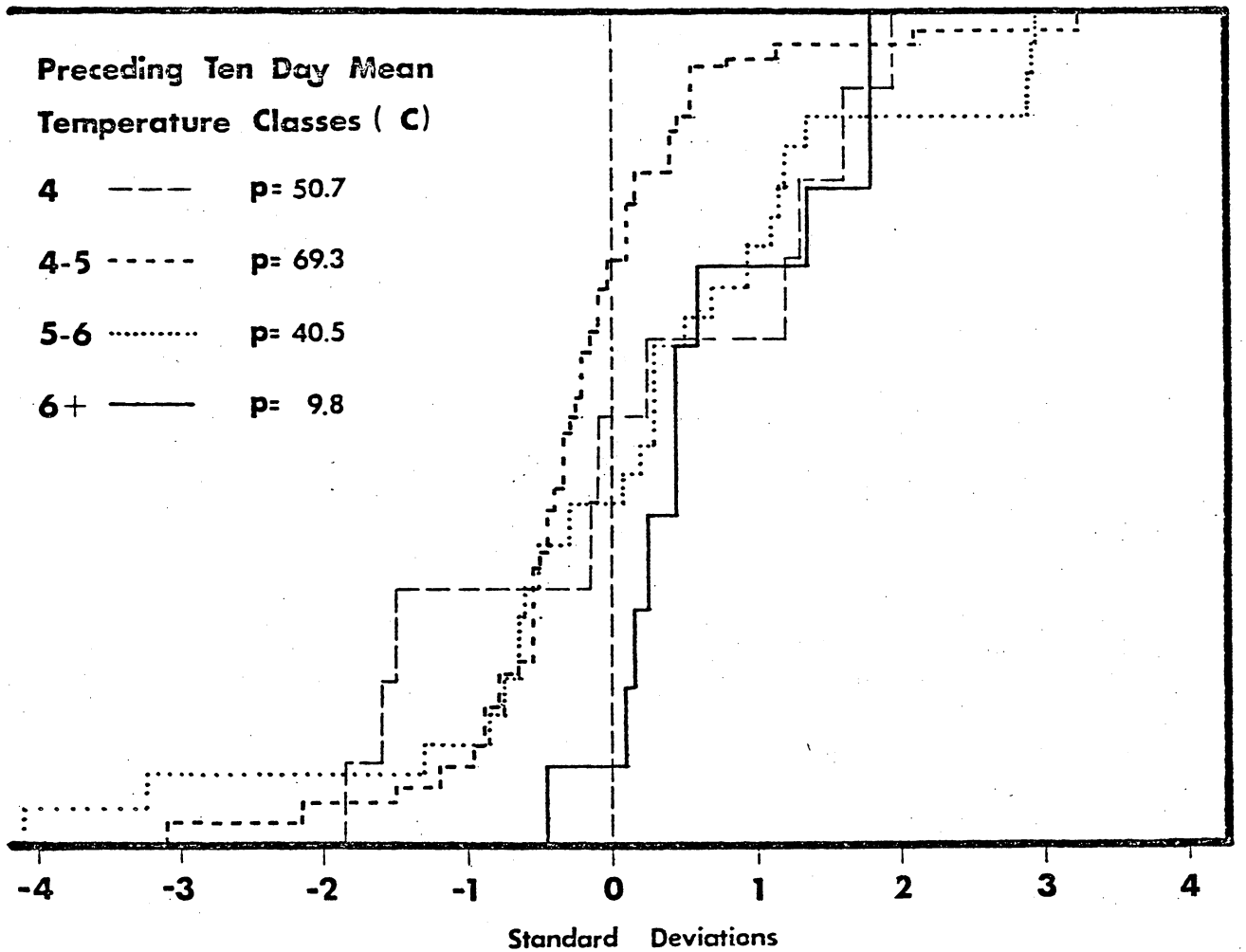
Fig. 64
Rim
Basin
Trough
Temperature
(degrees centigrade)
10
9
8
7
6
5
4
3
2
1
0
169
179
189
199
209
219
229
239
249
Julian Day 1973

in the 4-5 C temperature class. In other words, the 4-5 C temperature range, in which the greatest probability percent (69.3 %) of positive fungal hyphae growth was found, was determined from standing crop belowground fungal biomass. It might be suggested then that in a cool Arctic tundra ecosystem the fungi have adapted to the preponderance of cool summer soil temperatures such that growth and accumulation of the vegetative hyphae are commenserate with available substrate and other essential nutrients. To go beyond this point is certainly the task of the physiologist.

From Fig. 65, only 10 % of the positive growth of hyphae was explained from soil temperatures of 6 C or above, 41 % was explained by a 5-6 C temperature range, 51 % was explained by temperatures up to 4 C and 69 % of positive growth was again explained by the 4-5 C temperature class. So it became apparent that a change in soil temperature, based on the previous cumulative 10 day means, has little effect on fungal hyphae growth rates in soil of Arctic tundra until a temperature range of 4-6 C is reached. Assuming no decrease in soil moisture and the nutrient pool, it must also be said that fungal growth and biomass would most assuredly increase if temperatures increased beyond 6 C. All soil fungi isolated from Barrow litter have thus far been mesophilic from culture studies in the VPI laboratories and for the most part temperate species, as shown by Flanagan and Scarborough (1973 and 1974). Soil fungi were, to a great extent, buffered from the rapid flucuations of diurnal temperatures by their location in the soil profile. The slow rise in overall soil temperature toward mid season was accompanied by an increase in

Figure 65. Standard cumulative distribution of preceding 10 day mean temperature classes (C) showing the probability of actual growth rates of fungal mycelium in soil as calculated from the sums of delta biomass through the 1973 season.

Fig. 65


Preceding Ten Day Mean
Temperature Classes (C)
4 p= 50.7
4-5 p= 69.3
5-6 p= 40.5
6+ p= 9.8
-4
-3
-2
-1
0
1
2
3
4
Standard Deviations
Growth Rate ≤ Plotted Value Probability

fungal biomass (Fig. 44). However, it was clear that subtle temperature changes in an otherwise cool environment obviously have little or no effect on fungal mycelium growth *per se*.

VIII Soil Carbon and Fungal Biomass

Combustion gas analyses of 11 cultured hyphae samples revealed a mean 46.44 % carbon value based on tissue dry weights. From this and the knowledge of belowground standing crop fungal biomass in m/gdws it became possible to correlate hyphae carbon with total substrate carbon within each habitat type at each depth in the soil profile. It was also desireable to know if the belowground fungal biomass held amounts of carbon in reserve that were appreciably less or greater than those percentages of carbon in the soil. Hence, the quality of the substrate as a carbon source for the filamentous fungi was of prime interest.

In the Barrow peat soil system, the total microbial terrestrial biomass is not known. Ausmus and Whitcamp (1974) have estimated that 8.29 % of the total soil carbon pool was immobilized by microbial populations in grassland soils. Relative to a loam soil this may well be a significant amount. In the Barrow ecosystem, total soil carbon of an almost totally organic peat showed 33.2 % at 1-2 cm and 24.5 % carbon by weight at 6-7 cm (Table 24). Basin habitats showed the greatest total carbon, 40.1 %, near the peat soil surface. Soil carbon percents in basins were followed by soils of meadows at 39.8 %. Trough habitat soils were 33.4 % carbon and were close to the seasonal mean of 33.2 % for all habitats. Rim habitats had a low C % of 26.5, and polygon tops were lowest with 23.3 % soil carbon (Table 24). Of this total carbon pool in Arctic tundra soils, the mycelium contained from .96 % to 1.30 % of that total soil carbon percent as determined by the formula:

$$C\ \% = \frac{g\ \text{fungal}\ C/m^2/cm}{g\ \text{soil}\ C/m^2/cm} \times 100$$

TABLE 24a

1972-1973 TUNDRA PEAT SOIL C N Analyses[1]

Plot	1-2			
	N	C %	N %	C:N
Over all average	47	33.17± 12.27	1.97±.78	16.84:1
Meadow	8	39.79± 2.01	2.52±.36	15.79:1
Trough	14	33.36± 11.38	1.84±.79	18.13:1
Rim	7	26.53± 16.32	1.49±1.03	17.81:1
Basin	10	40.17± 2.2	2.45±.2	16.4:1
Top	8	23.25± 15.29	1.45±.7	16.03:1

Table 24b

Plot	6-7			
	N	C %	N %	C:N
Over all average	47	24.51± 13.7	1.49± .88	16.45:1
Meadow	9	21.39± 9.15	1.08± .42	19.81:1
Trough	12	22.05± 14.82	1.87±1.74	11.79:1
Rim	7	18.75± 13.12	1.34± .99	13.99:1
Basin	10	38.38± 5.04	2.31± .57	16.61:1
Top	8	19.71± 14.92	1.21± .81	16.29:1

[1]Means, over-all and by habitat, of Appendix 11.

The storage of fungal carbon was relatively insignificant to the total soil carbon pool. One might expect little correlation then between fungi and soil carbon if expression as organic matter and/or substrate quality. When fungal carbon was regressed on total soil carbon, the results showed little or no correlation, r^2 = .0005 at 1-2 cm and .002 at 6-7 cm, between m/gdws and soil carbon %.

By comparison to hyphal tissues, 46.5 % of the dry weight, other fungal tissues showed less carbon. Gill tissue alone ranked second with a mean carbon percent of 46.0. Gill and cap tissues were 45.4 % carbon; cap tissue was 44.1 % carbon; sclerotia, hyphal tissue of Myriosclerotinia sulcata grown in situ, was 40.9 % C; the whole basidiocarp, including stipe tissue, was 40.4 %; and stipe tissue alone was 37.4 % carbon, the lowest value determined. The range from 37.4 to 46.5 % was not exceedingly great. These facts do point out that a slightly larger percentage of the weight of fungus tissue is carbon as compared to an equal weight of soil substrate. But as was already shown, the total carbon weight tied up by fungal tissues relative to the total carbon pool was of little consequence by contrast. The correlation of fungal carbon, based on m/gdws, to soil carbon showed some variation with respect to habitats. Generally, at 6-7 cm, a higher correlation of fungal length to total carbon percent was detected. The only exception to this was found at the 1-2 cm depth in trough habitats. Trough habitats at the 1-2 cm depth showed the greatest correlation of fungal carbon to soil carbon, r^2 = .225. This was followed by meadow, top, basin and rim habitats in that order. This was not surprising because trough habitats also showed

the greatest growth rates with small resident standing crop biomass and threrfore greater dependance on the carbon source since phosphorus and nitrogen were relatively high. Correlation of g/m^2 fungal carbon to soil carbon showed the habitats ranked meadows first followed by tops, basins and rims with trough habitats last at 6-7 cm depths. Therefore, the presence and abundance of belowground fungal biomass can not be explained in terms of organic matter or substrate quality alone as defined by total carbon percents in the organic peat soils determined by combustion and gas chromatography.

Other attempts were made to relate the presence of fungi to total carbon by analysing mycelial lengths and biomass data on a gram mycelium per gram organic matter basis (Widden, et al., 1972). It was suggested by Nagel de Boois and Jansen (1966) that fungal lengths per gram organic matter reflected the biomass of fungi per unit of substrate rather than per unit of total soil material. When regressions were attempted, no relationships could be discerned by Nagel de Boois and Jansen (1966), presumably because pH, moisture and organic matter content effectively removed the major source of variation according to Dowding and Widden (1974). They show correlation coefficients of mycelial length to be:

.6224 with pH;

.6701 with water;

.6661 with organic matter percent (OM).

Because Barrow soils were highly organic, it was logical to assume that correlating fungal lengths to OM % would be duplication of effort as the percent total soil carbon would, in affect, equal organic matter

percents.

The question then asked was, in what form was carbon required by soil fungi. It becomes likely that the bulk of the biomass, at least early in the season, was basically composed of fungi that use simple, soluable carbon sources such as amino acids and carbohydrates. These compounds would be quickly leached from plant tissues as they die and enter the nutrient pool. In contrast, the more slowly decomposed and utilized fractions of the litter, such as cellulose and lignin, remain. The latter fraction of the available litter may be covered up before being decomposed. Since anaerobic soil conditions often persist a few centimeters below the peat layer, organic materials may remain in a partially decomposed state for hundreds of years. Peat in this condition has actually been C^{14} dated at 2,000-10,000 years old (Brown and Sellmann, 1973). It is therefore probable to assume that fungal activity would be highly correlated with the easily absorbed and more available substrates and not with the total soil carbon percents.

TABLE 25

1972, 1973 AND 1974 MYCELIA VS SOIL CARBON %

CORRELATION COEFFICIENTS (r VALUES)

Habitat type	N	m Mycelia/ gdws		g Mycelia/m^2	
		1-2cm	6-7cm	1-2cm	6-7cm
Meadow	8	.316	.676	.447	.456
Trough	13	.474	-.130	.120	-.131
Rim	7	.041	.300	-.452	-.009
Basin	10	-.243	-.312	-.203	-.191
Top	8	.266	.511	-.387	-.219
1972	3	-.970	-.993	-.960	-.974
1974	5	.305	.238	-.845	.005
Over-All	46	.023	.046	-	-

IX Influences of Soil Phosphorus on Fungal Biomass

The work of Barél (pers. comm.) on phosphorus levels in tundra peat soils near Barrow, Alaska were summarized. Extrapolations of his data were made for the five habitat types as presented in Table 26. He showed that greater total P concentrations, which included inorganic, organic and labile forms, were found in soils of polygon trough habitats at a level of 27.4 mg $P/m^2/7$ cm. Values for other habitats followed: meadow habitats, 12.9 $mg/m^2/7$ cm; rim habitats, 10.2 $mg/m^2/7$ cm; and basin habitats, 9.4 $mg/m^2/7$ cm. The lowest P levels were found on top habitats and were approximately 7.0 $mg/m^2/7$ cm.

Fungal tissues (dry wt.) were approximately 0.9 % phosphorus. Hence, it would be logical to assume that P levels might explain a great deal of the interhabitat variation in belowground fungal biomass as was seen between habitats. What was not known was what P form, inorganic, organic or labile, was utilized by the fungi. When total P was regressed on fungal biomass, no close correlation was found. Labile P, the exchangeable and most readily available form of phosphorus in the soil (Barél, pers. comm.) to the fungus cells, was then regressed on fungal biomass. Polygon basin habitats showed a correlation to the labile P, $r^2 = .85$ (Fig. 66). Polygon rim and trough habitats, which also showed high P values, had r^2 values of .53 and .46 respectively (Fig. 66) based on a 10 day fungal biomass to phosphorus lag. In basin plot soils levels of fungal biomass, even though low, were partially explained in terms of phosphorus levels in the soil. But, because of other limiting factors such as low O_2 (Benoit, pers. comm.) and anaerobic conditions just below the surface peats in many areas, fungal growth and accumulation was inhibited.

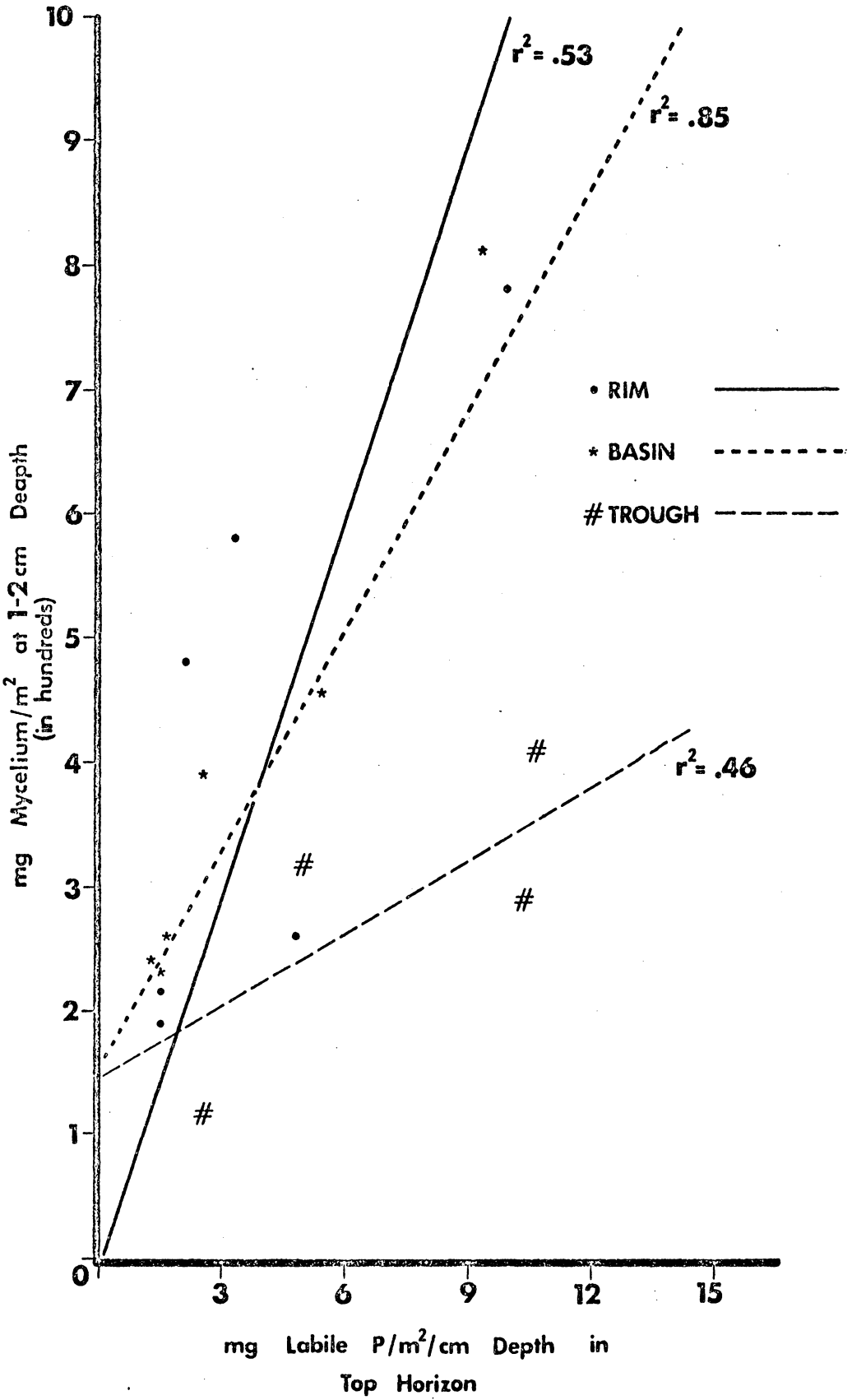
TABLE 26

Phosphorus[1] in Arctic Tundra Soils (mg/m^2)

Habitat	Depth in cm	mg Phosphorus/m^2				
		Total	Inorganic	Organic	Labile	Mean
Meadow (wet)	1-8	11.06	.56	10.5	14.43	9.14
Meadow (very wet)	1-8	19.25	1.48	17.77	28.35	16.71
Trough	1-8	25.89	2.16	23.98	57.61	27.41
Rim	1-8	11.3	.46	10.84	18.25	10.21
Basin	0-7	8.36	.44	7.8	21.09	9.42
Top (grassy	1-8	2.68	.25	2.43	21.38	6.69
Top (mossy)	1-8	10.29	.29	10.00	8.76	7.34

[1]Barél Data, 1974.

Figure 66. Fitted lines to r^2 values from the regression of fungal biomass (mg/m^2), taken from soils of the top horizons of rim, basin and trough habitats, on mg labile phosphorous per m^2 to 1 cm depths during 1973.


10
9
8
7
6
5
4
3
2
1
0
3
6
9
12
15
r^2 = .53
r^2 = .85
r^2 = .46
• RIM
* BASIN
# TROUGH
mg Mycelium/m^2 at 1-2 cm Depth (in hundreds)
mg Labile P/m^2/cm Depth in Top Horizon

X The Fungus Cell: Hyphal Widths

Extensive sampling of hyphal widths in tundra soils was conducted to determine mean widths of resident hyphal cells. It was important to obtain accurate measurements because of the need for a mean hyphal width in calculating belowground fungal biomass.

Results (Tables 27 and 28) showed that litter fungi in the Barrow region had an average diameter of 2.91 μm. Soil fungi showed a hyphal diameter average of 2.746 μm. A fungal hyphae diameter of 2.75 μm was used for all mathematical biomass (g/m^2, dry wt.) calcualtions of soil fungi.

Other investigators have used hyphal diameters of 2.2 μm (Doxtader, 1969), 2.5 μm (Babiuk and Paul 1970; Parkinson, 1970), 3.0 μm (Clark and Paul, 1970; Hayes, 1972; Nagel de Boois, 1970; Widden, 1971), 3.5 μm (Parkinson et al., 1971; Saito, 1955), 5 μm (Flanagan, pers. comm.; Hanssen et al., 1974), and 5.4 μm (Jackson, 1965) for soil fungi. The range of hyphal diameters used, 2.2 μm to 5.4 μm, by the investigators above were obtained from several major environments including tundra.

Nowhere in the literature have I found a standard mycelial diameter for soil or for litter fungi, but from a large number of samples of hyphal widths measured individual cells of 5 μm diameter were seldomly encountered in tundra soils near Barrow. Fungal cells were also measured in slide mounts using fresh soil and water. The measurements obtained were checked with samples mounted in hot water agar. In this way, any change in hyphal width resulting from methods of preparation would have been noted. There were no differences.

TABLE 27

1974 HYPHAL WIDTHS OF LITTER FUNGI BY HABITAT

Habitat	Hyphal	1-2 cm			6-7 cm		
		N	$\bar{x}$	sm	N	$\bar{x}$	sm
Meadow	Uncl	10	3.29	1.9	8	2.81	2.22
(416)	Clpd	0	0	0	0	0	0
Trough	Uncl	23	3.72	3.51	17	3.09	2.07
(424)	Clpd	0	0	0	4	2.53	.71
Rim	Uncl	32	3.04	1.55	19	2.53	.54
(426)	Clpd	19	3.12	1.04	6	2.60	.86
Basin	Uncl	12	4.03	2.53	4	2.25	.29
(428)	Clpd	0	0	0	0	0	0
Top	Uncl	14	3.06	1.97	6	2.03	1.55
(1233)	Clpd	6	2.65	.75	0	0	0
Seasonal		116	3.27		64	2.55	
Overall		180	2.91 µm				

TABLE 28

1974 HYPHAL WIDTHS OF SOIL FUNGI BY HABITAT

Habitat	depth			
	N	1-2 cm	N	6-7 cm
Meadow (416)	36	3.599	9	2.723
Trough (424)	63	2.476	29	2.6
Rim (426)	80	3.072	17	2.472
Basin (428)	22	3.041	4	2.25
Top (1233)	24	3.171	10	1.752
Seasonal	225	2.997	69	2.441
Overall	294	$\bar{x}$ = 2.75 µm		

Hence, there was justification for having to make hyphal width measurements from the haemacytometer slide preparations. Whenever one does quantitative fungal biomass research of this kind, the determination of hyphal diameters should have high priority and should be made prior to or during mycelial length measurements. Visser's (1971) results, from her work in Populus tremuloides Michx. litter (L), fermentive (F) and humus (H) layers, were good examples of this. Hyphal diameters ranged from 2.66 to 3.4 µm. Hyphal diameters measured averaged 2.66 µm in living leaves, 2.89 µm in surface litter, 2.4 µm in the F_1, 3.24 µm in the F_2 and 3.01 µm in the humus layer. Using an average value of 3.04 µm would have resulted in significant error in the biomass calculations of live leaf and F_1 horizons fungal biomass.

In Situ Growth

In situ hyphal growth was measured in capillary tubes over a 12 day period. Invasion and study of hyphal growth in the tubes was observed (Tables 29 and 30). An average growth of 295 µm resulted in two days of incubation after implanting the capillaries and the invasion of soil fungi had occurred. Hyphae that accumulated in the capillaries averaged 5,626 µm after 12 days of incubation during 1974. All hyphae were unclamped. Septate and non septate fungi were seen within the tubes. From the amount of mycelium found in the tubes, growth rates were determined for each of the five habitats. The results obtained during 1973, as shown in Tables 29 and 30, showed growth to be most rapid in soils of polygon rim habitats. Top, basin, trough and meadow habitats followed and in that order. Ordering of habitats

TABLE 29

1973 GROWTH OF SOIL FUNGI *IN SITU*[1]

Plot	Mean µ/day	Meters ($x10^{-4}$) per day	Habitat	µg hyphae (Dry wt.) per day	Growth (cells/day)
100	447.7	4.48		3.36	7.60
101	361.2	3.61		2.71	6.10
416	76.0	.76	Meadow	.57	1.30
417	441.8	4.42	Trough	3.32	7.40
418	233.0	2.33	Rim	1.75	3.90
426	560.0	5.60	Basin	4.20	9.50
428	270.0	2.70	Top	2.03	4.60

TABLE 30

1974 GROWTH OF SOIL FUNGI *IN SITU*[1]

Plot	Mean µ/day	Meters ($x10^{-4}$) per day	Habitat	µg hyphae (Dry wt.) per day	Growth (cells/day)
416	75.3	.75	Meadow	.56	1.28
424	267.8	2.68	Top	2.01	4.55
426	191.1	1.91	Trough	1.43	3.24
428	116.7	1.17	Rim	.88	1.98
1233	401.8	4.02	Basin	3.02	6.82

[1]At 1-2 cm depths.

using capillary growth figures was altered somewhat with top habitats again yielding the most rapid growth rates during 1974. Polygon tops were followed by trough, rim, basin and meadow habitats, which had the lowest capillary growth of soil fungi. Criteria such as time of sampling during the season, moisture conditions, temperature and other variables were assumed to have influenced the species of fungi which invaded the capillary tubes. These abiotic variables were also assumed to have had an effect on the rapidity of fungal invasion and the growth rates of the capillary hyphae. What influence these variables had on species, invasion and growth rates were not known nor was any of the variability in capillary growth rate accountable to any one variable more than to any other.

An overall habitat mean for 1974 capillary growth was 2,947 µm over a 12 day period. Data from 1973 (Table 29) showed higher values for similar habitats than were measured in 1974 (Table 30). Hyphal growth/day during 1973 was 2 X that measured in 1974. The average fungus cell length was determined to be ca. 58 µm long. This of course can only be said for septate hyphae. Thus, growth of the number of cells/habitat/day could be determined when only septate mycelia were considered.

Since a hypha branched approximately every 100 µm along its main trunk, septate or not, a model is herein proposed to calculate capillary tube biomass. If one assumes a steady growth rate the total combined length L_N of mycelium within the branching system and its biomass can be calculated as follows:

$$L_N = 1 \sum_{N=0}^{N-1} 2^n$$

$$= 1 \times \frac{1-2^N}{1-2}$$

where 1 = mean length between any two branches off the main trunk

L_t = trunk length only

N = total measured hyphal length in the mycelial system within the tube

$$= \frac{L_t}{1}$$

$$L_N = (1)\ \frac{1-2^{L_t/1}}{1-2}.$$

Example:

If $L_t = 450$ µm.

$1 = 100$ µm.

Then $N = \frac{450}{100} = 4.5$

$$L_N = (100)(\frac{1-2^N}{1-2})$$

$$= (100)\ (\frac{1-24.5}{1-1})$$

$$= (100)\ (\frac{-22.637}{-1})$$

$$= \underline{2,263.7\ \mu m}$$

Using total calculated mycelium lengths and a 80 µm growth rate per day, rather than main hyphal trunk lengths and cells/day, an estimate of the hyphal growth/day can be obtained from this capillary tube method.

Percent Colonization

Results obtained on colonization and relative growth of soil fungi in tundra soils (Table 32) were very similar to those found by Nagel de Boois and Hansen (1966) in mull and mor soils of England. Data from the Barrow ecosystem were preliminary. No replications were performed.

TABLE 31

COLONIZATION PERCENTS IN FIVE ARCTIC TUNDRA POLYGON HABITAT TYPES ON US IBP SITE 4 BARROW, ALASKA

Habitat type	Depth 1-2 cm	
	5 days %	10 days %
Meadow	4	17
Trough	2	3
Rim	12	19
Basin	2	3
Top	2	0

TABLE 32

1973 MEAN RELATIVE GROWTH RATES OF SOIL FUNGI (m/gdws) AT 1-2 cm BY HABITAT

Habitat	Total possitive growth ($+\Delta B$)	Seasonal mean biomass ($\bar{B}$)	$\frac{+\Delta \bar{B}}{\bar{B}}$
Meadow	1587 ± 1397	722 ± 395	2.16 ± 1.23
Trough	1401 ± 693	440 ± 159	3.28 ± 1.04
Rim	3624 ± 3312	1083 ± 595	2.81 ± 1.33
Basin	815 ± 490	577 ± 187	1.45 ± .76
Top	911 ± 427	390 ± 242	2.89 ± 1.49

[1]Include negative growth.

The data suggests that colonization rates of soil fungi increase with time. This, however, may not reflect natural in situ responses due to the effects of slicing the soil for insertion of the mesh and frame. Response of fungal growth to perturbation is shown in the literature to be positive. A short term experiment may merely reflect the response demonstrated by the fungi to the disturbances.

Initial results from the study support the hypothesis that colonization rates of new substrates were highest in soils of rim and meadow habitats and lowest in very wet or very dry soils found in troughs, basins or top habitats. Nagel de Boois and Jansen (1966) reported similar percents for mesh colonization in two mull and one mor soils from an oak forest in England. They reported percents ranging from 5.1 to 15.4 % My data show a range of 2 to 19 %.

Growth Rate

Growth rates of fungi were determined in soils from each of the five habitats by summing the positive and negative changes in standing crop fungal biomass through the season and dividing that biomass sum (ΔB) by the mean standing crop biomass, $\bar{B}$.

The data (Table 32) from rim habitats showed the greatest positive biomass change (ΔB), 3624 m/gdws, at the 1-2 cm depth. This indicator of positive growth was better than 2.24 X greater than the ΔB found in soils of meadow habitats, 1587 m/gdws, and almost 3 X greater than the ΔB found in soils of trough habitats, 1401 m/gdws. Top and basin habitat soils maintained the lowest ΔB, 911 and 815 m/gdws respectively, almost 4 X less than the ΔB found in soils of rim habitats (Table 32).

When considering the mean standing crop biomass, $\bar{B}$, of each

habitat in comparison to ΔB, the growth rate, there were major shifts in emphasis between habitats (Table 32). For instance, trough habitats showed a $+\Delta B$ of 1401 m/gdws, a value lower than either meadow, 1587 m/gdws, or rim habitats, 3624 m/gdws. The mean standing crop of fungi, $\bar{B}$, in soils of troughs was 440 m/gdws, much lower than $\bar{B}$ of meadows, 722 m/gdws, or rims, 1083 m/gdws. Growth rate , $\frac{+\Delta B}{\bar{B}}$, of soil fungi in trough habitats was 3.28, which was greater than fungal growth rates from either rim, 2.81, or meadow, 2.16, habitats (Table 32). Polygon low center basin habitats showed a growth rate of 1.45, again the lowest in keeping with the lowest $+\Delta B$. This suggests, from a relatively high $\bar{B}$ and a suspected low turnover activity, as suggested from the deep peat layer soil, that the greater proportion of hyphae in basin habitats might either be dead, inactive or deficient in some essential nutrient. Phosphorus must be excluded, however, as labile P concentrations in the basin habitats were higher than in soils of any other habitat type. Labile P data, the exchangeable and most readily available P source to the soil fungi, showed the highest correlation, $r^2 = .85$, to $\bar{B}$ in the basin habitats. Polygon high center top habitats, which showed the lowest $\bar{B}$ and a low $+\Delta B$, also showed a growth rate of 2.89, a value slightly greater than was found in soil fungi on rim habitats, 2.81. This might suggest that basidiomyceteous hyphae from rim soils, which were probably in greater abundance than the 9.2 % clamped value recorded in Table 31, have a greater percentage of living versus dead cells within the total mean biomass, $\bar{B}$. The basidiomycetes might account for the majority of the turnover in soils of any habitat even though the hyphae were slower growing and have a

low $\bar{B}$ in soils of polygon top habitats. This may be perhaps to some nutrient deficiency other than total soil carbon or some abiotic factor such as moisture.

Nutrient Content

Dominant species of Arctic basidiomycetes and ascomycetes were selected and analyzed for total carbon and nitrogen content (Table 33). Fungi were selected because of the availability of pure cultures of the species, which allowed comparisons of basidiocarp tissues to be made with vegetative hyphae grown in culture (Table 33). It was not possible to gather fungal hyphae of a particular species from the soil for analysis. One must rely on data obtained from results using cultured hyphae. The presence of sclerotia, hard knots of fungus hyphal tissue belonging to the cup fungus Myriosclerotinia sulcata, allowed me to analyze vegetative mycelium of one species, which in fact grew in situ. The C:N ratio of tissue from the sclerotium was very similiar to the C:N ratio of fungal hyphae grown in pure culture. Neither, however, was as high as C:N ratios of sporocarp tissues. The C:N ratio data lend credence to the support for the use of C:N values from sclerotia to express total C:N ratios in fungal hyphae over the moisture gradient.

The C N analyses of fungal hyphae showed .07-.82 g N (total)/m^2 for 0-7 cm. Flint and Gersper (1974) estimated exchangeable ammonia nitrogen (NH_3-N) in similar peat soils to be .27 g/m^2/cm or 1.89 g/m^2/7 cm. From the data, it became apparent that fungal cells may well be important as a nitrogen sink and therefore a source of nitrogen for the slow and timely release of that nitrogen into the ecosystem.

Nitrogen levels in fungal tissues were highest in gill tissue, 6.43 %, lowest in sterile tissues of the stipe, 1.85 %, and sclerotia, 1.66 %, but only moderately low in hyphae grown in culture, 2.75 % (Table 33). The high *in vitro* nitrogen level may indeed be a result of the rich culture medium. Fruiting bodies, and specifically the hymenium, had high nitrogen contents and contained almost four times the nitrogen found in the vegetative mycelium of the same species (Table 33).

Fungal tissues, representative of whole agaric basidiocarps, contained rather substantial quantities of total phosphorus in comparison to nitrogen (Table 34). Levels of phosphorus ranged from 3.1 mg P/g of dry fungus tissue to 17.6 mg P/g. Very close mean P values of 9.29 mg P/g and 9.35 mg P/g were obtained from 15 fungus samples using two different methods. Data from nitric-perchloric acid digestion/oxidation methods of P determination resulted in the former 9.29 mg/g value. Data obtained from digestion of fungal tissues at 500 C in magnesium acetate solution resulted in the 9.35 mg/g mean value. Values of fungal P for mycorrhizal species, 5.8 mg/g, for decomposer species, 12.3 mg/g, and for basidiolichen species, 6.6 mg/g, were impressive when compared to labile P concentrations in tundra soils.

The overall average soil bulk density for Arctic peat soils was approximately .2 g/cc. A block of soil, 1 m^2 X 7 cm deep, would therefore weigh approximately 14000 g. Barél and Barsdate (1974) found mean levels of total soil phosphorus to be approximately 12.7 mg/m^2/7 cm (Table 26) or .00009 % by weight. Average fungus tissue total phosphorus was .932 % by weight, a 10^4 increase of phosphorus in fungal tissues over an equal weight of soil in the Barrow region. This

TABLE 33

Mean % C and N in Fungal Tissues

Tissue[1]	N	%				C/N Ratio
		C	CV	N	CV	
B	11	40.41	9.2	6.03	21.2	7.09
B_1	13	45.39	13.9	5.48	30.4	9.27
B_2	4	44.13	.7	4.86	33.6	10.12
B_3	4	45.96	8.0	6.43	18.6	7.36
B_4	2	37.37	14.5	1.85	43.3	23.05
H	11	46.45	9.2	2.75	52.0	19.99
S	1	40.87	-	1.66	-	24.62

[1] B Cap, gills and stipe

B_1 Cap and gills only

B_2 Cap only

B_3 Gills only

B_4 Stipe only

H Hyphae, cultured

S Sclerotia, in situ

TABLE 34

Phosphorus Analysis of Whole Basidiocarps of Arctic Fungi

Group[1]	Collection number	Binomial	Total Phosphorus mg/g Method A[2]	Method B[3]
*	OKM/GAL 11603	Cortinarius huronensis	7.5	7.5
*	OKM/GAL 11611	C. mucosus	3.2	3.1
*	OKM/GAL 11605	Hebeloma pusillum	7.0	6.9
*	OKM/GAL 11602	Lactorius lanceolatus	6.9	6.7
*	OKM/GAL 11600	Russula emetica	4.1	4.6
#	OKM/GAL 11601	Clitocybe polygona	13.0	13.2
#	OKM/GAL 11639	Clitocybe polygona	12.6	12.9
#	OKM/GAL 11637	Coprinus martinii	12.8	13.0
#	OKM/GAL 11609	Galerina subannulata	16.6	16.4
#	OKM/GAL 11614	Galerina subannulata	13.2	12.3
#	OKM/GAL 11607	Hypholoma udum	7.7	7.9
#	OKM/GAL 11615	Hypholoma udum	4.5	4.5
#	OKM/GAL 11635	Omphalina pyxidata	17.3	17.6
&	OKM/GAL 11623	Omphalina ericetorum	7.7	7.9
&	OKM/GAL 11618	Omphalina hudsoniana	5.3	5.3
		overall mean =	9.29	9.35

Mean * N = 5 $\bar{x}$ = 5.8 cv% = 33

Mean # N = 8 $\bar{x}$ =12.3 cv% = 35

Mean & N = 2 $\bar{x}$ = 6.6 cv% = 27

[1]Group * = mycorrhizal species; # = decomposer species; & = basidiolichens.

[2]Method A = Nitric/Perchloric Acid digestion and oxidation.

[3]Method B = Digestion by dry ashing @ 500°C with Mg - acetate solution.

supports the hypothesis that the mycelium component, and more importantly the basidiocarps of fungi, act as nutrient sinks for nutrients other than nitrogen.

Caloric Content

Results of oxygen bomb calorimetry showed caloric contents of fungal tissues (Table 35) to range from 3790 to 4900 cals./gdw of fungus tissue with an average of 4290 cal/g, a value close to that found in vascular plant tissues (Tieszen, pers. comm.). Generally, those fungi found to be mycorrhizal associates, and therfore on higher and dryer tundra soils, showed higher caloric values than did fungi from wetter habitats.

TABLE 35

Fungal Fruiting Body Caloric Concentrations (cal/gdw)

Collection number	Taxon	calories/g
Basidiomycetes		
OKM/GAL 10889	Amanita vaginata	4471.5
OKM/GAL 10889	Amanita vaginata	4269.6
OKM/GAL 10316	Lactarius lanceolatus	4352.4
OKM/GAL 10514	Russula emetica var. alpestris	4410.3
OKM/GAL 10556	Russula emetica var. alpestris	4410.3
OKM/GAL 10975	Russula emetica var. alpestris	4232.9
OKM/GAL 10566	Russula xerampelina var. pascua	4332.8
OKM/GAL 11025	Russula xerampelina var. pascua	4321.4
OKM/GAL 10982	Hygrophorus citrinopallidus	4395.2
OKM/GAL 10511	Clitocybe sp.	4359.2
OKM/GAL 10511	Clitocybe sp.	4464.2
OKM/GAL 10511	Clitocybe sp.	4438.2
OKM/GAL 10511	Clitocybe sp.	4409.9
OKM/GAL 10513	Cystoderma amianthinum var. typicum	4365.6
OKM/GAL 10513	Cystoderma amianthinum var. typicum	4312.9
OKM/GAL 10594	Cystoderma amianthinum var. typicum	4228.9
OKM/GAL 10707	Omphalina luteovitellinia	4405.7
OKM/GAL 10920	Omphalina pyxidata	3789.9
OKM/GAL 10554	Galerina subannulata	4269.4
OKM/GAL 10604	Galerina subannulata	4045.5
OKM/GAL 10606	Galerina subannulata	4045.5
OKM/GAL 10515	Leccinum scaber	4426.4
OKM/GAL 10505	Leccinum scaber	4616.8

TABLE 35 Continued

Collection number	Taxon	Calories/g
OKM/GAL 10522	Lycoperdon umbrinum	4899.0
Ascomycetes		
OKM/GAL 10897	Helvella corium	4206.7
OKM/GAL 10897	Helvella corium	4217.1
OKM/GAL 10640	Myriosclerotinia sulcata	3987.1
OKM/GAL 10650	Myriosclerotinia sulcata	3944.4
Mean =		4290.5

GENERAL DISCUSSION AND CONCLUSIONS

Of the many studies on soil fungi where belowground fungal mycelium biomass has been e phasized using direct observation agar film counting techniques, this study is to date the most comprehensive. At the time of its initiation quantitative fungal biomass studies in an Arctic tundra soil ecosystem had not been attempted. During the four year interim between the initiation of my research in 1971 and its completion in 1974 three similar studies in Arctic tundra soils were started. The studies by Hanssen and Goksøyr (1974) in Norway and Sweden, Hayes (1972) in Sweden, and Widden (1972) in Canada, were also completed under the auspices of the IBP. Their works have resulted in no publication in the open literature as yet.

The intensity of their monthly sampling can not compare with my own. Hanssen and Goksøyr (pers. comm.) examined 25 samples from five Hardangervidda plots in Norway during 1972 and 48 samples from two Stordalen sites in Sweden in 1972-1973. Hayes (1972) examined 50 samples from 2 Stordalen sites and 60 samples from the Njulla site, both in Sweden. Widden (1972) examined 8 samples from four Devon Island sites in the Canadian Arctic archipelago. By contrast, I have examined a total of 1217 samples and 57,850 microscopic fields. Samples were taken every ten days over 3 field seasons from the period of thaw to freeze up. The sample cores were taken from 38 plots representing 5 major undisturbed sites and 3 disturbed sites.

I justify this intense and concentrated sampling for a number of reasons clearly enumerated in the objectives section of this dissertation. I reiterate. First, the season was short and the zone of

activity within the soil system was narrow, ca. 4-5 cm. Fungal biomass was found to show a great deal of inherent variability within the short season and the shallow zone of activity. An analysis of variance between four replicate and contiguously extracted soil cores showed that several hundred fields would have had to be read to yield a 5 % error margin at the 95 % confindence level. This was impossible because of the man hours involved so a 36 % error margin at the 95 % confidence level was accepted such that 50 fields per soil sample had to be counted. Hence, the reason for the large number of fields counted. The number of samples was large because of the number of habitats, disturbed and undisturbed, that characterized the 1400 m moisture dominated gradient. I wanted to know what was happening biologically along the whole gradient within the many defineable habitats. In short, I saw great potential for accomplishing much in the way of integrated research with limited time by addressing myself to fascinating questions relative to what might very well be the principle decomposers, the fungi, within the Barrow ecosystem.

Second, to fit my particular interests in soil fungi into the integrated research program of terrestrial decomposition, I sought; 1) to obtain seasonal belowground standing crop fungal biomass to elucidate fluctuations and seasonal trends, 2) to demonstrate biomass trends within the soil profile down to the depth of thaw, 3) to determine relative growth rates of hyphae, 4) to ascertain the importance of soil moisture, soil bulk density and temperature on the growth and colonization rates of fungi, 5) to determine the roles of fungi in Arctic tundra relative to higher plant communities, and 6) to

determine the relative importance of fungi as nutrient sinks for C, N and P in otherwise nutrient poor tundra soils.

At the time of the initiation of this work, a firmly held misconception about fungi existed. Higher fungi were thought to be rare or even lacking in Arctic tundra ecosystems. This misconception has long since been put to rest (Miller et al., 1972). The standing crop fungal biomass in the tundra soil averaged about 700 m/gdws/cm and 1.05 $g/m^2/cm$ dry weight or 7.4 g/m2/7 cm. Fungal lengths in the Barrow tundra system, as described in the site and plots descriptions, were approximately 1/7 to 1/8 of those found per g day soil in Sweden's Stordalen sites, 7-8 times greater than those lengths found in the three Norway sites at Hardengervidda and comparable to lengths of soil hyphae found at the four Canadian sites on Devon Island. On a $g/m^2/cm$ basis, the biomass of soil fungi (dry wt.) at Barrow was comparable to all other Arctic soil fungi biomass figures. The Stordalen and Njulla sites at Abisko, Sweden showed a range from 2.2 to 5.8 $g/m^2/cm$. Barrow values were 1/2 to 1/3 of those reported by Hanssen and Goksøyr (pers. comm.) from the two Swedish sites.

Barrow hyphae were smaller, 2.75 μm compared to 3.5 μm, less dense, 1.1 g/cc versus 1.3 g/cc, and had less dry weight composition, 11.5 % to 17 %, as compared to soil hyphae found in Swedish tundra. It must be assumed then that soil bulk densities at the Swedish and Norwegian sites must have been much less than the average .35 g/cc found on the Site 4 moisture gradient at Barrow during the 1973 season. One must consider carefully the life zone to fully understand these differences between tundra sites, all of which were not always Arctic,

ex.g. the Hardangervidda, Norway site where fungal biomass ranged from 7-18 g/m^2/cm.

'Life zone' here is defined as the vertical zone from the canopy heights of the vegetation to the depth of thaw of the active layer, which lies above the permafrost. In Barrow, this 20-40 cm zone was the zone of most if not all biological activity. My attention was directed to the soil surface and the first 4-5 cm of soil. This was the zone of greatest activity in the ecosystem where the greatest standing crop of fungal biomass and the greatest fluctuation of that biomass responded to hydrologic phenomenon and climatic factors that (Flint and Gersper, 1974) were found. Kormondy (1969) pointed out that 76 % of the total biomass in shrubby tundra was belowground and that a total productivity of about 2500 kg/ha/yr., or about 250 g/m^2/yr., was produced belowground. In the Barrow ecosystem, the total belowground biomass has been estimated to be approximately 90 % of the total. Productivity of above ground plant parts has been estimated at 1000 kg/ha/yr., or 100 g/m^2/yr. (P. Miller, pers. comm.). Total belowground biomass was pretty much limited to the top 4-5 cm of peat soil. It was in the upper 4-5 cm of soil that the bulk of the fungal biomass was also found. There substrate was available for the fungi, most of which were docomposer or mycorrhizal forming fungi. I have shown that the fungal biomass was little influenced by temperature, but then temperature was essentially a surface phenomenon and remained more or less constant within the soil. Litter fungi would surely respond more directly to temperature, wind dessication and relative humidity than would the deeper soil fungi. Soil fungi do respond to

soil moisture, perhaps the single most important variable that influenced the belowground fungal biomass, and the reason for selecting the study sites along an elevational moisture gradient. The concept of the Arctic life zone then becomes more meaningful in relation to soil fungi when placed in perspective.

As few as 50 miles south of Barrow the tundra ecosystem changes noticeably, but so does the life zone. The rhizosphere penetrates several centimeters into the soil unlike the 4-5 cm penetration near Barrow. Fungal biomass follows the nutrient sources downward. At Mead River, soil fungi were concentrated at 10-15 cm depths. The life zone widened. In a temperate grassland ecosystem, the life zone widens such that soil fungi have been detected 90 cm below the surface (Doxtader, 1969). However, fungal biomass ($g/m^2/cm$) was only 3-4 times greater than that found in the Barrow Arctic 'grassland' even when dry weights of temperate fungi equaled 20 % as compared to 11.5 % in the Barrow ecosystem. In a coniferous (Pinus contorta) forest biome, Widden and Parkinson (1974, 1975) have shown a narrower soil life zone where fungal hyphae were heavily concentrated in the A_1 horizon. This was due to the presence of a shallow rhizosphere and an impenetrable podzol soil. Similar declines in fungal biomass below 5 cm were experienced in Arctic tundra soils near Barrow because of the silty mineral soil layers so aptly described by Flint (pers. comm.). Even then, soil fungal biomass in a coniferous forest was only two times greater than the 1973 Barrow average. Biomass in soils of rim habitats near Barrow surpassed Widden and Parkinson's (1974 and 1975) values for the coniferous forest ecosystem. Soils of

these three biomes, tundra, conifer forest and grasslands, and probably most others as well, maintained a fairly stable resident fungal biomass not as different from each other as one might expect.

The advantage of knowing levels of standing crop fungal biomass in a soil system lies within its predictive potentials. Several facts about the fungus cell are now known and when combined with biomass data they permit one to make predictions about the tundra ecosystem relative to the fungi. First, we know hyphae are nutrient sinks for moderate amounts of carbon, for substantial amounts of nitrogen and for large quanties of phosphorus relative to the amounts of each of the three nutrients in the peat soil. Second, the dominant role of filamentous fungi in Barrow tundra is that of decomposer as shown by the clamped and unclamped data, relative abundance, and the habitat and ecological studies of fruiting basidiocarps. Third, growth and colonization rates of Arctic tundra soil fungi in a variety of habitats along the moisture gradient have been determined. Changes in biomass, capillary tubes and nylon mesh experiments, have yielded valuable information on growth and on colonization rates of tundra soil fungi. One meter of initial hyphae, over a growing season of 100 days, will produce 2.5 m/yr./m initial hyphae as determined from <u>in situ</u> capillary tube experiments. Ten thousand hyphal growing tips/m of hyphae were determined from a model that allowed the calculation of fungal production within capillary tubes. Summation of all positive and negative changes in standing crop fungal biomass during the 1973 season showed 2.8 m/yr./m of hyphae were produced. Hanssen and Godsøyr (pers. comm.) predicted from their tundra studies that 1.0-1.5 m/yr./m hyphae were

produced at a growth rate of 0.1 μm/min taken from Burnett (1968). Given a 100 day season, this would be ½ the rate of production found in tundra soils near Barrow, Alaska. The fact that no one has successfully determined death rates of soil fungi limits the accuracy of any prediction, however. To perfect the NBT vital staining/counting technique of living vs dead hyphae would be a substantial stride forward in the study of soil fungi and thus adding to the predictiveness of decomposition study rates within an ecosystem. Certainly, the modified counting and measuring technique that has been perfected here would allow its use in any system.

Standing crop fungal biomass must also be considered in relation to the nutrients available in the system and to nutrients held within fungal tissues. A fungal mycelium production rate of about 2.7 m/yr./m would require 2.6 % to 3.5 % of the total peat soil carbon source as determined for the Barrow system. Carbon was therefore a non limiting substrate, which suggests why practically no correlation between fungal biomass and organic matter % or carbon % was determined from the regression analysis. This production rate would also require 0.19-2.2 g or ½ to slightly more than all of the exchangeable (NH_3) ammonium nitrogen available. Exchangeable nitrogen was a very small proportion of the total nitrogen pool. This suggests that soil fungi in Barrow use NO_2^-, and NO_3^- nitrogen when it is available, particularly in soils of polygon rim and top habitats where biomass is large and the amount of NH_3-N is low. Barél (1974) has shown that all three of these N forms were present in Barrow tundra. The 2.7 m/yr./m fungal production rate would also require a substantial amount, if not more than the

total, of the net available soil phosphorus. Basidiocarp tissues have been shown to hold 3 times more P than was available in the soil. Large concentrations of P in fungi suggests that fungal tissues may act as sinks and thus greatly influence the turnover rates of P cycling with respect to perhaps the single most important and limiting element in the Barrow tundra ecosystem.

Attempts were made to estimate turnover rates of filamentous fungi in soils of the Barrow ecosystem. What was obtained was a production rate of circa 2.7 m/yr/initial meter of soil hyphae. Turnover rates of soil fungi still remain an inigma to investigators.

Several soil invertebrates viz. mites, colembola, enchytraeid worms and insect larvae graze on fungi (Douce, pers. comm.). How much energy they receive has not been answered, but gut content studies have shown that fungal filaments account for up to 50 % of ingested matter in some invertebrates (Douce, pers. comm.).

Caloric studies showed that fungal tissues contained 3790 to 4900 cals/gdw fungus tissue (whole basidiocarps) for a mean of 4290 cal/g, or about 4300 cal/m^2 based on standing crop belowground fungal biomass. The caloric content of fungi was comparable to that of higher plant cells. Organisms which graze on soil fungi also receive about 10 % lipids and 90 % proteins as well as carbohydrates according to Cochrane (1958). Carbohydrates may be insignificant in amount, but they are present as has been shown from caloric studies.

Decomposition studies using artificial and natural substrates have been completed in a number of Biomes and in the Tundra Biome as reviewed by Roswall (1974) from 14 sites in several countries.

Artificial substrates used in tundra studies were pure cellulose strips (non bleached sulphite pulp), which allowed for cotton strip and filter paper comparisons of decomposition rates between circumpolar tundra sites. Fourty-one types of natural substrates were used, as the dominant vegetation type was selected and used from each of the sites. Resulting rates of decomposition varied from 2-90 % the first year (Heal, 1971). Roswall (1971) determined rates of decomposition of Rubus litter at 26.2 % wt. loss the first year while Empetrum litter only lost 5-7 %. Heal and Latter (1971) have shown that Calluna stems loose 20-25 % the first year, whereas Calluna shoots and Eriophorum leaves lost about 50 %. This translates to a time of 10-60 years for 95 % of the litter to decompose. In the Barrow system complete decomposition has been estimated to be near 100 years (Heal, 1971). No one knows what portion of these decomposition rates result from filamentous fungi alone. This suggests that a larger fungal biomass standing crop may be needed to turnover the litter over a longer time period and at a much slower rate in an Arctic ecosystem as compared to a temperate system. This is suggested from relatively large standing crop fungal biomass in tundra soils as compared to more southerly sites that have been investigated.

Decomposition rates of cellulose were determined in other studies using a host of abiotic and biotic parameters. When temperature, soil pH, nitrogen and time in days were used in multiple regression analyses, only 29 % of the variablility in decomposition rates were exaplained (Heal, 1971). The point was that moisture levels had the single most important abiotic influence on fungal biomass presence and abundance

in my studies, yet soil moisture was not used by Heal in the above mentioned regressions. Lohammar and Roswall (1973) have shown, using the Abisco Model of Bunnell and Dowding (1974), that litter moisture contents appeared to be the driving force for decomposition in the Swedish litter bag studies.

Decomposition, in general, was also shown to be much more rapid in the surface soil profiles of Arctic and Subarctic tundra. This conformed to my soil fungi data in that greater proportions of the standing crop fungal biomass were found in the top 4 cm of the soil profile. If fungal biomass is several times greater than bacterial biomass, the fungi would perform most if not all of the decomposition. However, from the literature, one obvious comparison was lacking. Fungal biomass has never been correlated with studies of decomposition rates. Decomposition studies are often long term studies and again in no other tundra environment was fungal biomass as well known as it was for U.S. Arctic tundra. No longer can it be said that yeasts are 10 times greater in biomass than filamentous fungi (Brown, 1971) as was determined by plating isolation techniques prior to this study. Many of the fungi present in Barrow peat soils, particularly the basidiomycetes, simply can not be cultured using a standard plating technique. Several conclusions were drawn from the most intensive study of soil fungi in a cold dominated Arctic tundra ecosystem.

1. The standing crop fungal biomass of 700 m/gdws, as determined from a three year period, was comparable to other Arctic tundra opt. cit., and also to belowground fungal biomass in other than Arctic tundra biomes, e.g. grasslands and coniferous forest.

2. The fluctuations of fungal biomass were most pronounced near the soil surface. They showed vernal highs, declines to a mid season low, with an increased biomass to the period of fungal fruiting, and general decrease to freeze-up, a trend common to other Arctic as well as temperate soil systems.
3. Variations in biomass were greater in the surface soil layers, 1-2 cm, as compared to those found at 6-7 cm, where a relatively constant and much lower resident fungal biomass was detected.
4. Belowground standing crop fungal biomass declined appreciably with increased depth within the soil profile, a trend common to the findings of other investigators in all biomes studied.
5. The presence of soil fungi was not greatly influenced by total soil carbon or soil organic matter %. Belowground fungal biomass was greatly influenced by soil moisture percents, and to a much lesser extent, temperature, where the greatest correlation of standing crop fungal biomass change and growth was associated with the 4-5 C temperature class.
6. Fungal biomass was optimal, relative to C, N, P, temperature, growth, hyphal width, soil bulk density, soil moisture (dry wt. %), the presence of clamps and colonization rates, in soils of rim habitats. Meadow, trough, basin and top habitats followed and in that order.
7. Soil bulk density was important in expressing biomass on a m^2 basis, and it influenced fungal biomass physically by affecting the particle space relationships in the soil. The effects of bulk density on fungal biomass (m/gdws) can not

be separated from soil moisture. The influence of soil moisture on fungal biomass was significant and was separable from that of soil bulk density.

8. The roles of fungi within the Arctic tundra ecosystem were those of the decomposer (saprophyte) and the mycorrhizal associate with higher vascular plants. Very few parasitic fungi were found.

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APPENDICES

APPENDIX 1

TABLE 1

1972 MYCELIUM MEANS BY PLOT[1]

Plot	Mycelium			
	meters/g soil	g/m^2	$g\ C/m^2$	$g\ N/m^2$
138	0.00	0.000	.0000	.00000
400	565.20	1.378	.0678	.00379
414	832.54	0.832	.0411	.00240
416	1472.37	2.709	.1334	.00780
417	661.12	1.405	.0692	.00405
418	370.36	0.459	.0226	.00132
419	467.37	1.336	.0659	.00385
420	524.36	0.812	.0399	.00234
421	907.81	1.327	.0653	.00382
422	614.57	1.227	.0604	.00354
423	347.76	0.790	.0389	.00228
424	737.34	1.037	.0512	.00299
425	1053.61	4.078	.2008	.01174
426	742.11	2.760	.1359	.00795
427	2229.33	3.473	.1710	.01000
428	604.63	0.834	.0411	.00240
430	1458.42	3.679	.1815	.01059
440	563.53	1.778	.0875	.00512
450	69.67	0.483	.0238	.00139

[1]Plot means include both 1-2 and 6-7cm depths and seven sample days on US IBP TB Sites, Barrow, Alaska.

TABLE 2

1973 MYCELIUM MEANS BY PLOT[1]

Plot	Mycelium			
	meters/g soil	g/m^2	g C/m^2	g N/m^2
100	262.52	0.286	.0141	.00082
101	328.91	.0496	.0244	.00143
200	662.65	0.833	.0410	.00240
400	249.14	0.553	.0272	.00159
414	374.38	0.370	.0182	.00107
415	453.75	0.401	.0197	.00115
416	738.01	1.137	.0560	.00327
417	1258.45	2.651	.1306	.00764
418	323.17	0.445	.0219	.00128
419	327.95	0.818	.0403	.00236
420	430.61	0.598	.0295	.00172
421	630.87	1.029	.0507	.00296
422	394.74	0.740	.0364	.00213
423	355.48	0.637	.0314	.00183
424	384.80	0.343	.0169	.00099
425	771.82	1.865	.0919	.00537
426	1062.86	2.724	.1342	.00785
427	2931.03	4.338	.2137	.01249
428	434.11	0.558	0.275	.00161
440	419.05	0.409	.0202	.00118
441	351.62	0.883	.0435	.00254
442	255.51	0.444	.0219	.00128
1232	397.46	1.237	.0610	.00356
1233	88.69	0.536	.0264	.00154

[1]Plot means include all days (11) and depths (7) on US IBP TB Site moisture gradient, Barrow, Alaska. A m^2 is a 1cm wafer $1m^2$.

TABLE 3

1974 MYCELIUM MEANS BY PLOT[1]

Plot	Mycelium			
	meters/g soil	g/m^2	% unclamped	% clamped
416	1414.3	2.48	82.1	17.9
424	600.9	1.61	94.9	5.1
426	1439.9	5.27	82.2	17.8
428	454.9	.74	99.0	1.0
1233	153.2	.47	99.8	.2

[1]Plot means include all depths from five sample days on US IBP Tundra Biome Sites Barrow, Alaska.

TABLE 4

1972 SOIL BULK DENSITY MEANS BY PLOT[1]

FOR 1-2CM AND 6-7CM DEPTHS

Plot	Bulk Density
138	.407
400	.316
414	.159
415	.185
416	.297
417	.398
418	.340
419	.407
420	.232
421	.352
422	.449
423	.439
424	.251
425	.623
426	.557
427	.216
428	.207
430	.297
440	.462
450	.949

[1]Plot means include all depths (2) and days (7) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 5

1973 SOIL MEANS BULK DENSITY BY PLOT[1]

Plot	Bulk Density
100	.192
101	.383
200	.304
400	.330
414	.147
415	.168
416	.254
417	.395
418	.378
419	.436
420	.224
421	.328
422	.434
423	.420
424	.201
425	.600
426	.588
427	.222
428	.196
440	.186
441	.468
442	.249
1232	.448
1233	.953

[1]Plot means include all depths (7) and days (11) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 6

1974 SOIL BULK DENSITY MEANS BY PLOT[1]

Plot	Bulk Density
416	.416
424	.607
426	.425
428	.304
1233	.716

[1]Plot means include all depths from five sample days on US IBP Tundra Biome Sites Barrow, Alaska.

TABLE 7

1972 SOIL MOISTURE (WET AND DRY WT.) MEANS BY PLOT[1]

Plot	Soil Moisture	
	Wet Wt. %	Dry Wt. %
138	48.00	164.7
400	68.60	391.7
414	80.74	537.5
415	78.13	457.5
416	71.28	306.2
417	58.72	178.2
418	65.38	373.3
419	53.78	123.2
420	70.85	252.4
421	64.06	217.0
422	55.71	168.4
423	55.74	203.1
424	74.94	498.2
425	52.74	163.6
426	44.18	088.0
427	69.03	228.3
428	73.12	299.9
430	76.45	328.8
440	59.89	172.1
450	22.00	029.1

[1]Plot means include all depths (2) and days (7) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 8

1973 SOIL MOISTURE (WET AND DRY WT.) MEANS BY PLOT[1]

Plot	Soil Moisture	
	Wet Wt.%	Dry Wt.%
100	80.6	509.8
101	65.4	288.3
200	72.4	356.8
400	68.1	284.3
414	83.6	576.1
415	82.5	557.8
416	74.3	346.9
417	63.9	232.7
418	68.6	378.7
419	61.8	200.8
420	77.6	366.7
421	70.8	326.5
422	63.2	229.2
423	66.4	349.3
424	81.1	627.9
425	55.8	204.2
426	52.9	168.5
427	77.2	373.5
428	79.7	425.7
440	81.6	579.0
441	63.7	233.6
442	75.4	320.3
1232	57.6	150.4
1233	21.0	032.0

[1]Plot means include all depths (7) and days (11) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 9

1974 SOIL MOISTURE PERCENT BY PLOT[1]

Plot	Moisture	
	Wet Wt.	Dry Wt.
416	67.8	270.8
424	60.5	264.1
426	64.0	206.0
428	73.2	314.4
1233	27.9	50.0

[1] Plot means include all depths from five sample days on US IBP Tundra Biome Sites, Barrow, Alaska.

APPENDIX 2

TABLE 1

1972 MEANS ALL VARIABLES BY DEPTH[1]

Variable	Depth	
	1-2cm	6-7cm
m Mycelium/g soil (dry wt.)	1105.66	370.78
g Mycelium/m^2	1.841	1.177
g Mycelium C/m^2	.091	.058
g Mycelium N/m^2	.005	.003
Soil bulk density (g/cc)	.239	.487
g Soil/m^2	2384.95	4871.15
g Soil C/m^2	884.94	1807.44
g Soil N/m^2	55.808	113.985
Soil moisture (wet wt. %)	.732	.525
Soil moisture (dry wt. %)	3.808	1.574

[1]Depth means include all plots (17) and days (7) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 2

1973 MEANS ALL VARIABLES BY DEPTH[1]

Variable	Depth						
	0-1[2]	1-2	2-3	3-4	4-5	5-6	6-7
m Mycelium/g soil (dry wt.)	1063.52	814.65	742.52	632.75	357.76	302.78	272.98
g Mycelium/m^2	1.244	1.210	1.315	1.206	.892	.892	.783
g Mycelium C/m^2	.061	.060	.065	.059	.044	.044	.039
g Mycelium N/m^2	.0036	.0035	.0038	.0035	.0026	.0026	.0023
Soil bulk density (g/cc)	.172	.236	.301	.360	.429	.510	.508
g Soil/m^2	1718.01	2363.91	3007.20	3597.02	4291.13	5098.06	5079.88
g Soil C/m^2	637.47	877.13	1115.82	1334.68	1592.22	1891.64	1884.89
g Soil N/m^2	40.20	55.32	70.37	84.17	100.41	119.30	118.87
Soil moisture (wet wt. %)	.806	.754	.729	.691	.649	.593	.581
Soil moisture (dry wt. %)	5.165	4.356	3.922	3.408	2.779	2.096	1.984

[1]Depth means included all plots (24) and days (11) on the US IBP TB Site moisture gradient, Barrow, Alaska.

[2]Soil profile depths in cm.

TABLE 3

1974 MEANS ALL VARIABLES BY DEPTH[1]

Variable	Depth	
	1-2cm	6-7cm
m Mycelium/g soil (dry wt.)	1803.4	210.8
g Mycelium/m^2	3.153	1.218
g Mycelium C/m^2	.156	.06
g Mycelium N/m^2	.009	.003
Soil bulk density (g/cc)	.316	.749
g Soil/m^2	3160.0	7490.0
g Soil C/m^2	1172.5	2779.2
g Soil N/m^2	73.9	175.3
Soil moisture (wet wt. %)	70.2	47.4
Soil moisture (dry wt. %)	364.7	128.2

[1]Depth means include all plots (17) and days (7) on the US IBP TB Site moisture gradient, Barrow, Alaska.

APPENDIX 3

TABLE 1

1972 MYCELIUM MEANS BY DAY FOR A 1CM WAFER $1m^2$

AT 1-2CM AND 6-7CM DEPTHS

Julian[1] day	Mycelium			
	meters/g soil	g/m^2	g C/m^2	g N/m^2
171	1222.66	2.397	.118	.00690
181	1041.99	1.802	.089	.00519
195	702.63	1.683	.083	.00485
209	675.75	1.480	.073	.00426
226	866.94	1.515	.075	.00436
237	645.22	1.329	.066	.00383
251	371.62	0.725	.036	.00209

[1]Julian day 171 is 20, June 1972, 166 is 15, June 1973.

TABLE 2

1973 MYCELIUM MEANS BY DAY TO A 7CM DEPTH For 1cm

Julian[1] day	Mycelium			
	meters/g soil	g/m^2	g C/m^2	g N/m^2
166	300.82	1.057	.052	.00304
169	720.15	1.419	.070	.00409
179	941.23	1.291	.064	.00372
189	658.38	1.071	.053	.00309
199	439.29	0.871	.043	.00251
209	403.44	0.791	.039	.00228
219	589.84	1.124	.055	.00324
229	556.15	1.178	.058	.00339
234	482.34	1.184	.058	.00341
249	556.57	0.712	.035	.00205
267	630.37	0.886	.044	.00255

[2]Day means include all plots (17 in 1972, 24 in 1973) and depths (2 in 1972, 7 in 1973)on the US IBP TB Sites, Barrow, Alaska.

TABLE 3

1974 MYCELIUM MEANS BY DAY[1] FOR

1-2CM AND 6-7CM DEPTHS

Julian day	Mycelium	
	meters/g soil	g/m^2
231	1281.7	3.004
241	483.4	1.236
251	970.9	1.971
261	567.5	1.736
271	1824.1	2.363

TABLE 4

1974 SOIL MOISTURE PERCENTS BY DAY[1] FOR

1-2CM AND 6-7CM DEPTH

Julian day	Soil moisture	
	Wet wt.	Dry wt.
231	59.2	242.8
241	55.6	176.2
251	61.2	274.1
261	55.6	200.9
271	82.8	483.7

[1]Day means include all plots (5 in 1974) and depths on US IBP TB Sites, Barrow, Alaska.

TABLE 5

1972 SOIL MOISTURE PERCENT (WET AND DRY WT.) MEANS BY DAY[2] FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTH

Julian[1] day	Soil moisture	
	(Wet wt.)	(Dry wt.)
171	.7898	544.1
181	.7071	390.0
195	.5926	207.8
209	.5999	211.1
226	.6171	263.1
237	.6246	261.4
251	.6472	301.5

[1]Julian day 171 is 20, June 1972, and 166 is 15, June 1973.

TABLE 6

1973 SOIL MOISTURE PERCENT (WET AND DRY WT.) MEANS BY DAY[2] FOR A 1CM WAFER $1m^2$ TO A 7CM DEPTH

Julian[1] day	Soil moisture	
	(Wet wt.)	(Dry wt.)
166	.253	036.8
169	.534	161.1
179	.738	418.6
189	.713	375.6
199	.712	363.6
209	.665	306.5
219	.661	303.2
229	.671	330.3
234	.657	291.8
249	.728	379.7
267	.726	357.0

[2]Day means include all plots (17 in 1972, 24 in 1973) and depths (2 in 1972, 7 in 1973) on the US IBP TB Site Moisture gradient, Barrow, Alaska.

TABLE 7

1972 SOIL MEANS BULK DENSITY FOR a 1CM WAFER 1m ^{2} AT 1-2CM and 6-7cm DEPTH BY DAY

Julian[2] day	Bulk density
171	.272
181	.300
195	.387
209	.380
226	.372
237	.382
251	.313

TABLE 8

1973 SOIL MEANS BULK DENSITY FOR a 1CM WAFER 1m ^{2} AT 1-2CM and 6-7CM DEPTH BY DAY

Julian[2] day	Bulk density
166	.628
169	.410
179	.292
189	.308
199	.336
209	.382
219	.354
229	.416
234	.425
249	.246
267	.241

[1]Day means include all plots (17 in 1972, 24 in 1973) and depths (2 in 1972, 7 in 1973) on the US IBP TB Site moisture gradient, Barrow, Alaska.

[2]Julian day 171 is 20, June 1972, and 166 is 15, June 1973.

TABLE 9

1974 SOIL BULK DENSITY BY DAY[1]

Julian day	Bulk density
231	.540
241	.511
251	.494
261	.586
271	.190

[1]Day means include all plots (5 in 1974) and depths on US IBP TB Sites, Barrow, Alaska.

APPENDIX 4

TABLE 1

1972 MYCELIUM SEASONAL MEANS BY PLOT-DEPTH[1] FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS

Plot	Depth in cm	Mycelium			
		m/g soil	g/m^2	C/m^2	N/m^2
138	2	0.00	0.000	.0000	.00000
138	7	0.00	0.000	.0000	.00000
400	2	520.00	0.797	.0392	.00230
400	7	610.39	1.959	.0965	.00564
414	2	1170.80	0.835	.0413	.00241
414	7	494.28	0.828	.0409	.00239
415	2	753.90	0.561	.0277	.00162
415	7	196.21	0.420	.0207	.00121
416	2	2524.89	4.250	.2093	.01224
416	7	419.85	1.167	.0576	.00336
417	2	1088.57	1.800	.0885	.00518
417	7	233.66	1.011	.0498	.00291
418	2	649.74	0.527	.0260	.00152
418	7	90.99	0.390	.0192	.00112
419	2	561.85	1.174	.0578	.00338
419	7	372.89	1.499	.0740	.00432
420	2	774.78	1.037	.0510	.00298
420	7	273.94	0.587	.0288	.00169
421	2	1660.21	2.021	.0993	.00582
421	7	155.41	0.633	.0313	.00182
422	2	1126.52	1.938	.0955	.00558
422	7	102.61	0.516	.0253	.00149
423	2	582.12	1.032	.0508	.00297
423	7	113.41	0.547	.0270	.00158
424	2	1028.35	0.866	.0427	.00249
424	7	397.82	1.238	.0610	.00357

[1]Plot-depth means include all days (7) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 1 Continued

Plot	Depth in cm	Mycelium			
		m/g soil	g/m^2	C/m^2	N/m^2
425	2	1546.80	4.568	.2248	.01316
425	7	560.42	3.588	.1768	.01033
426	2	1189.93	3.907	.1923	.01125
426	7	358.26	1.777	.0876	.00512
427	2	2711.68	3.586	.1765	.01033
427	7	1746.97	3.361	.1655	.00968
428	2	959.01	1.204	.0593	.00347
428	7	250.26	0.464	.0229	.00134
430	2	685.58	1.154	.0570	.00332
430	7	2231.27	6.203	.3060	.01786
440	2	939.53	2.817	.1385	.00811
440	7	187.53	0.739	.0365	.00202
450	2	79.50	0.453	.0223	.00131
450	7	59.84	0.512	.0253	.00147

TABLE 2

1972 SEASONAL SOIL BULK DENSITY MEANS BY PLOT-DEPTH FOR A 1CM WAFER $1m^2$ AT 1-2CM and 6-7CM depths

Plot	Depth in cm	Bulk density
138	2	0.278
138	7	0.535
400	2	0.204
400	7	0.427
414	2	0.095
414	7	0.223
415	2	0.099
415	7	0.285
416	2	0.224
416	7	0.370
417	2	0.220
417	7	0.576
418	2	0.108
418	7	0.571
419	2	0.278
419	7	0.535
420	2	0.178
420	7	0.285
421	2	0.162
421	7	0.542
422	2	0.229
422	7	0.669
423	2	0.236
423	7	0.642
424	2	0.112
424	7	0.414

[1]Plot-depth means include all days (7) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 2 Continued

Plot	Depth in cm	Bulk density
425	2	0.393
425	7	0.852
426	2	0.437
426	7	0.660
427	2	0.176
427	7	0.256
428	2	0.167
428	7	0.247
430	2	0.224
430	7	0.370
440	2	0.399
440	7	0.524
450	2	0.759
450	7	1.138

TABLE 3

1972 SOIL MOISTURE (WET AND DRY WT.) MEANS BY PLOT-DEPTH[1] FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
138	2	.752	3.032
138	7	.208	0.262
400	2	.824	6.012
400	7	.548	1.822
414	2	.865	6.996
414	7	.750	3.754
415	2	.859	6.349
415	7	.690	2.506
416	2	.793	3.952
416	7	.632	2.172
417	2	.721	2.640
417	7	.453	0.925
418	2	.845	5.738
418	7	.463	1.728
419	2	.584	1.487
419	7	.492	0.978
420	2	.749	3.010
420	7	.668	2.039
421	2	.763	3.244
421	7	.519	1.097
422	2	.732	2.728
422	7	.383	0.641
423	2	.766	3.526
423	7	.349	0.537
424	2	.875	7.281
424	7	.603	2.299

[1]Plot-depth means include all days (7) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 3 Continued

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry Wt.
425	2	.713	2.723
425	7	.342	0.550
426	2	.526	1.216
426	7	.340	0.593
427	2	.733	2.761
427	7	.628	1.806
428	2	.778	3.687
428	7	.685	2.310
430	2	.789	3.735
430	7	.740	2.840
440A	2	.693	2.357
440A	7	.505	1.086
450	2	.229	0.308
450	7	.211	0.274

TABLE 4

1973 MYCELIUM SEASONAL MEANS BY PLOT-DEPTH[1] FOR A 1CM WAFER $1m^2$

Plot	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	N/m^2
100	2	389.85	0.357	.0176	.00103
100	7	135.18	0.214	.0105	.00062
101	2	598.24	0.738	.0263	.00213
101	7	59.57	0.254	.0125	.00073
200	1	852.62	1.031	.0508	.00297
200	2	1194.35	1.231	.0607	.00355
200	3	732.17	1.047	.0516	.00302
200	4	514.88	0.718	.0254	.00207
200	5	385.01	0.554	.0273	.00160
200	6	182.15	0.430	.0212	.00124
200	7	240.44	0.479	.0236	.00138
400	1	493.84	0.600	.0295	.00173
400	2	187.20	0.267	.0131	.00077
400	3	174.36	0.401	.0198	.00116
400	4	194.27	0.488	.0240	.00141
400	5	149.87	0.320	.0158	.00092
400	6	379.27	1.201	.0592	.00346
400	7	264.12	0.782	.0385	.00225
414	1	516.33	0.466	.0229	.00134
414	2	462.59	0.346	.0170	.00100
414	3	725.41	0.592	.0291	.00171
414	4	460.61	0.452	.0223	.00130
414	5	359.00	0.458	.0225	.00132
414	6	241.44	0.328	.0162	.00094
414	7	132.74	0.249	.0123	.00072

[1]Plot and depth means include all days (11).

TABLE 4 Continued

Plot	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	g N/m^2
415	1	1342.15	0.995	.0490	.00287
415	2	677.69	0.406	.0249	.00146
415	3	453.39	0.379	.0187	.00109
415	4	260.14	0.237	.0117	.00068
415	5	350.33	0.382	.0188	.00110
415	6	122.78	0.211	.0104	.00061
415	7	104.30	0.208	.0102	.00060
416	1	1262.86	1.514	.0746	.00436
416	2	1112.56	1.839	.0906	.00530
416	3	1642.71	2.214	.1091	.00638
416	4	982.68	1.442	.0710	.00415
416	5	284.78	0.431	.0213	.00124
416	6	283.29	0.506	.0249	.00145
416	7	108.05	0.293	.0144	.00084
417	1	1647.08	1.861	.0917	.00536
417	2	1990.94	3.217	.1584	.00926
417	3	2322.21	5.689	.2802	.01638
417	4	1909.24	5.328	.2624	.01534
417	5	630.94	2.361	.1163	.00680
417	6	380.51	2.034	.1002	.00586
417	7	273.41	0.824	.0406	.00237
418	1	824.33	0.557	.0275	.00161
418	2	438.87	0.363	.0179	.00104
418	3	344.33	0.682	.0336	.00197
418	4	280.71	0.651	.0321	.00187
418	5	72.68	0.299	.0148	.00086
418	6	45.10	0.208	.0103	.00060
418	7	210.86	0.480	.0236	.00138

TABLE 4 Continued

Plot	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	g N/m^2
419	1	462.96	0.786	.0387	.00226
419	2	572.88	1.064	.0524	.00307
419	3	273.46	0.725	.0357	.00209
419	4	181.79	0.659	.0325	.00190
419	5	144.37	0.669	.0329	.00192
419	6	162.89	0.730	.0360	.00210
419	7	166.68	0.691	.0341	.00199
420	1	1390.12	1.459	.0719	.00420
420	2	613.45	0.809	.0399	.00233
420	3	415.01	0.657	.0324	.00189
420	4	312.09	0.473	.0233	.00136
420	5	170.06	0.286	.0141	.00082
420	6	202.10	0.433	.0213	.00125
420	7	135.64	0.281	.0138	.00081
421	1	1627.79	1.814	.0894	.00522
421	2	1064.56	1.320	.0650	.00380
421	3	353.14	0.483	.0238	.00139
421	4	502.62	0.733	.0361	.00211
421	5	201.98	0.760	.0374	.00219
421	6	307.70	0.846	.0417	.00244
421	7	250.90	0.908	.0447	.00261
422	1	1516.64	1.729	.0852	.00498
422	2	511.20	0.838	.0413	.00241
422	3	394.57	0.770	.0279	.00222
422	4	261.56	0.736	.0363	.00212
422	5	278.98	0.823	.0405	.00237
422	6	156.15	0.636	.0313	.00183
422	7	66.90	0.309	.0152	.00089

TABLE 4 Continued

Plot	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	g N/m^2
423	1	1045.40	1.022	.0504	.00294
423	2	543.86	0.929	.0458	.00267
423	3	309.94	0.527	.0259	.00152
423	4	246.65	0.682	.0336	.00196
423	5	272.75	0.506	.0249	.00146
423	6	126.47	0.282	.0139	.00081
423	7	92.51	0.400	.0197	.00115
424	1	298.46	0.252	.0124	.00072
424	2	426.96	0.410	.0202	.00118
424	3	282.22	0.183	.0090	.00053
424	4	401.65	0.280	.0138	.00080
424	5	127.33	0.100	.0049	.00029
424	6	129.45	0.198	.0098	.00057
424	7	203.93	0.509	.0251	.00147
425	1	1727.88	1.862	.0917	.00537
425	2	952.65	1.732	.0853	.00499
425	3	579.74	1.463	.0721	.00421
425	4	651.61	2.173	.1070	.00626
425	5	1064.25	2.788	.1373	.00803
425	6	792.95	2.462	.1213	.00709
425	7	271.86	1.523	.0750	.00438
426	1	1539.22	2.888	.1423	.00832
426	2	1380.32	3.173	.1563	.00914
426	3	2185.20	4.313	.2125	.01242
426	4	970.88	1.517	.0747	.00437
426	5	778.56	2.104	.1036	.00606
426	6	516.98	2.565	.1264	.00739
426	7	560.87	2.339	.1152	.00674

TABLE 4 Continued

Plot	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	g N/m^2
427	1	3567.03	3.924	.1933	.01130
427	2	3458.09	4.239	.2088	.01221
427	3	3226.04	4.469	.2201	.01287
427	4	4018.18	5.988	.2950	.01724
427	5	1846.50	4.018	.1979	.01157
427	6	2390.32	5.203	.2553	.01499
427	7	1921.71	3.814	.1879	.01098
428	1	867.62	1.050	.0517	.00303
428	2	742.67	0.864	.0426	.00249
428	3	199.87	0.270	.0133	.00078
428	4	393.36	0.494	.0244	.00142
428	5	219.38	0.302	.0149	.00087
428	6	297.67	0.538	.0265	.00155
428	7	155.49	0.267	.0132	.00077
440	1	546.17	0.410	.0202	.00118
440	2	549.09	0.392	.0193	.00113
440	3	514.36	0.436	.0215	.00126
440	4	312.50	0.334	.0165	.00096
440	5	136.72	0.170	.0084	.00049
440	6	64.79	0.112	.0055	.00032
440	7	462.56	0.621	.0306	.00179
441	1	865.35	1.323	.0652	.00381
441	2	428.41	0.851	.0419	.00245
441	3	160.70	0.328	.0162	.00095
441	4	388.72	0.851	.0419	.00245
441	5	357.76	1.136	.0559	.00327
441	6	145.65	0.624	.0308	.00180
441	7	205.21	0.955	.0471	.00275

TABLE 4 Continued

Plot	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	g N/m^2
442	1	375.35	0.589	.0290	.00170
442	2	374.46	0.590	.0291	.00170
442	3	322.15	0.558	.0275	.00161
442	4	225.55	0.377	.0186	.00109
442	5	145.05	0.252	.0124	.00073
442	6	161.58	0.325	.0160	.00094
442	7	139.65	0.324	.0160	.00093
1232	1	515.95	0.977	.0481	.00281
1232	2	482.17	1.333	.0657	.00384
1232	3	571.95	1.730	.0852	.00498
1232	4	359.19	1.252	.0617	.00361
1232	5	279.81	1.040	.0512	.00299
1232	6	247.92	1.009	.0497	.00291
1232	7	316.50	1.195	.0589	.00344
1233	1	112.36	0.252	.0124	.00073
1233	2	116.01	0.607	.0299	.00175
1233	3	151.46	1.011	.0498	.00291
1233	4	90.60	0.658	.0324	.00190
1233	5	110.74	0.897	.0442	.00259
1233	6	19.75	0.186	.0092	.00054
1233	7	48.95	0.366	.0180	.00105

TABLE 5

1973 SEASONAL SOIL BULK DENSITY MEANS BY PLOT-DEPTH[1]

Plot	Depth in cm	Bulk density
100	2	.121
100	7	.264
101	2	.176
101	7	.590
200	1	.169
200	2	.182
200	3	.180
200	4	.207
200	5	.209
200	6	.593
200	7	.516
400	1	.181
400	2	.204
400	3	.327
400	4	.338
400	5	.413
400	6	.510
400	7	.427
414	1	.097
414	2	.095
414	3	.107
414	4	.134
414	5	.163
414	6	.177
414	7	.222

[1]Plot and depth means include all days (11).

[2]Depth 2=1-2cm, 7=6-7cm etc.

TABLE 5 Continued

Plot	Depth in cm	Bulk density
415	1	.106
415	2	.099
415	3	.114
415	4	.123
415	5	.161
415	6	.231
415	7	.286
416	1	.159
416	2	.224
416	3	.190
416	4	.203
416	5	.206
416	6	.251
416	7	.370
417	1	.170
417	2	.221
417	3	.345
417	4	.420
417	5	.495
417	6	.581
417	7	.576
418	1	.107
418	2	.108
418	3	.278
418	4	.503
418	5	.597
418	6	.728
418	7	.571
419	1	.219
419	2	.278

TABLE 5 Continued

Plot	Depth in cm	Bulk density
419	3	.421
419	4	.607
419	5	.640
419	6	.580
419	7	.535
420	1	.148
420	2	.178
420	3	.212
420	4	.204
420	5	.226
420	6	.280
420	7	.285
421	1	.153
421	2	.162
421	3	.179
421	4	.201
421	5	.402
421	6	.558
421	7	.542
422	1	.168
422	2	.229
422	3	.265
422	4	.467
422	5	.582
422	6	.600
422	7	.669
423	1	.181
423	2	.236
423	3	.404

TABLE 5 Continued

Plot	Depth in cm	Bulk density
423	4	.405
423	5	.418
423	6	.575
423	7	.642
424	1	.094
424	2	.112
424	3	.086
424	4	.098
424	5	.110
424	6	.247
424	7	.414
425	1	.142
425	2	.393
425	3	.434
425	4	.626
425	5	.789
425	6	.874
425	7	.852
426	1	.350
426	2	.437
426	3	.645
426	4	.665
426	5	.759
426	6	.814
426	7	.660
427	1	.145
427	2	.176
427	3	.230
427	4	.248

TABLE 5 Continued

Plot	Depth in cm	Bulk density
427	5	.305
427	6	.292
427	7	.256
428	1	.169
428	2	.167
428	3	.167
428	4	.165
428	5	.185
428	6	.230
428	7	.248
440	1	.105
440	2	.097
440	3	.123
440	4	.143
440	5	.165
440	6	.271
440	7	.314
441	1	.202
441	2	.266
441	3	.287
441	4	.322
441	5	.641
441	6	.735
441	7	.752
442	1	.194
442	2	.212
442	3	.243
442	4	.234
442	6	.268
442	7	.315

TABLE 5 Continued

Plot	Depth in cm	Bulk density
1232	1	.247
1232	2	.400
1232	3	.409
1232	4	.463
1232	5	.493
1232	6	.532
1232	7	.524
1233	1	.272
1233	2	.759
1233	3	.969
1233	4	1.140
1233	5	1.201
1233	6	1.217
1233	7	1.138

TABLE 6

1973 SEASONAL MEANS FOR SOIL MOISTURE (WET AND DRY WT.) BY PLOT AND DEPTH[1]

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
100	2	.859	6.585
100	7	.752	3.611
101	2	.818	4.768
101	7	.491	0.997
200	1	.837	5.127
200	2	.780	4.539
200	3	.807	4.211
200	4	.794	3.917
200	5	.760	3.228
200	6	.534	1.650
200	7	.611	2.243
400	1	.819	4.964
400	2	.765	4.147
400	3	.690	2.263
400	4	.669	2.020
400	5	.648	2.100
400	6	.521	1.180
400	7	.609	2.007
414	1	.884	7.720
414	2	.854	6.446
414	3	.879	7.315
414	4	.865	6.478
414	5	.841	5.385
414	6	.818	4.550
414	7	.783	4.119

[1]Plot and depth means include all days (11).

TABLE 6 Continued

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
415	1	.877	7.164
415	2	.868	7.032
415	3	.881	7.458
415	4	.872	6.852
415	5	.837	5.224
415	6	.760	3.275
415	7	.737	3.160
416	1	.821	4.608
416	2	.769	4.373
416	3	.800	4.043
416	4	.791	3.827
416	5	.773	3.435
416	6	.742	2.937
416	7	.645	2.064
417	1	.810	4.491
417	2	.719	3.089
417	3	.704	2.898
417	4	.652	2.324
417	5	.595	1.623
417	6	.531	1.178
417	7	.522	1.227
418	1	.881	7.463
418	2	.858	6.558
418	3	.734	3.370
418	4	.604	2.304
418	5	.538	1.404
418	6	.463	0.893
418	7	.562	1.877

TABLE 6 Continued

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
419	1	.766	3.307
419	2	.692	2.917
419	3	.625	1.790
419	4	.532	1.226
419	5	.518	1.132
419	6	.538	1.197
419	7	.567	1.359
420	1	.823	4.715
420	2	.815	4.440
420	3	.800	4.016
420	4	.785	3.657
420	5	.764	3.252
420	6	.744	2.909
420	7	.725	2.824
421	1	.838	5.326
421	2	.817	4.526
421	3	.816	4.460
421	4	.791	3.838
421	5	.665	2.422
421	6	.554	1.804
421	7	.557	1.496
422	1	.808	4.244
422	2	.776	3.677
422	3	.732	2.882
422	4	.591	1.646
422	5	.542	1.327
422	6	.477	1.032
422	7	.489	1.015

TABLE 6 Continued

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
423	1	.834	7.022
423	2	.784	5.283
423	3	.724	4.772
423	4	.674	3.084
423	5	.653	2.750
423	6	.566	1.807
423	7	.502	1.045
424	1	.895	8.787
424	2	.885	7.913
424	3	.897	8.817
424	4	.887	8.076
424	5	.866	6.926
424	6	.763	3.925
424	7	.653	2.925
425	1	.845	5.476
425	2	.673	2.820
425	3	.630	2.305
425	4	.525	1.633
425	5	.470	1.320
425	6	.433	1.021
425	7	.404	0.748
426	1	.695	2.926
426	2	.587	1.996
426	3	.540	1.878
426	4	.511	1.740
426	5	.489	1.619
426	6	.469	1.339
426	7	.454	1.081

TABLE 6 Continued

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
427	1	.824	5.188
427	2	.792	4.192
427	3	.781	3.966
427	4	.763	3.548
427	5	.719	2.604
427	6	.730	2.702
427	7	.752	3.145
428	1	.834	5.431
428	2	.814	4.839
428	3	.829	4.981
428	4	.823	4.767
428	5	.787	3.741
428	6	.772	3.554
428	7	.758	3.215
440	1	.889	8.315
440	2	.876	7.596
440	3	.867	6.772
440	4	.859	6.250
440	5	.839	5.274
440	6	.747	3.665
440	7	.717	3.542
441	1	.784	3.687
441	2	.738	3.048
441	3	.742	3.118
441	4	.734	3.128
441	5	.544	1.642
441	6	.511	1.357
441	7	.476	1.066

TABLE 6 Continued

Plot	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
442	1	.806	4.451
442	2	.774	3.523
442	3	.759	3.199
442	4	.753	3.081
442	5	.757	3.178
442	6	.741	2.896
442	7	.714	2.545
1232	1	.701	2.360
1232	2	.587	1.678
1232	3	.602	1.523
1232	4	.584	1.407
1232	5	.575	1.352
1232	6	.559	1.285
1232	7	.522	1.209
1233	1	.461	0.864
1233	2	.300	0.513
1233	3	.198	0.254
1233	4	.141	0.165
1233	5	.126	0.144
1233	6	.129	0.149
1233	7	.117	0.136

TABLE 7

1974 MYCELIUM SEASONAL MEANS BY PLOT-DEPTH FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS

Plot	Depth in cm	Mycelium	
		meters/g soil	g/m^2
416	2	3268.7	4.326
	7	131.5	.862
424	2	1600.3	1.870
	7	229.9	1.965
426	2	3503.9	8.105
	7	444.9	1.955
428	2	922.7	1.314
	7	174.4	.423
1233	2	231.8	1.052
	7	75.8	.597

TABLE 8

1974 SOIL BULK DENSITY MEANS BY PLOT-DEPTH FOR A 1CM WAFER $1m^2$ AT 1-2CM and 6-7CM DEPTHS

Plot	Depth in cm	Soil bulk density
416	2	.178
	7	.859
424	2	.156
	7	.845
426	2	.331
	7	.566
428	2	.181
	7	.327
1233	2	.641
	7	1.001

TABLE 9

1974 SOIL MOISTURE PERCENT MEANS BY PLOT-DEPTH FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS[1]

Plot	Depth in cm	Soil moisture	
		Wet wt. %	Dry wt. %
416	2	82.2	465.4
	7	47.9	88.0
424	2	85.2	579.4
	7	52.7	171.7
426	2	72.8	284.1
	7	55.8	130.6
428	2	83.0	501.8
	7	72.6	266.4
1233	2	32.3	65.1
	7	32.0	19.3

[1]On US IBP TB Sites Barrow, Alaska.

APPENDIX 5

TABLE 1

1972 SEASONAL MYCELIUM MEANS BY DAY-DEPTH[1]
FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS

Julian days	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	g N/m^2
171	2	1592.54	2.616	.1289	.00753
181	2	1431.52	1.750	.0863	.00504
195	2	1016.17	1.913	.0942	.00551
209	2	1059.39	1.751	.0862	.00504
226	2	1320.31	1.982	.0976	.00571
237	2	1011.26	1.874	.0923	.00540
251	2	615.28	1.017	.0501	.00293
171	7	704.83	2.089	.1028	.00602
181	7	701.14	1.847	.1028	.00532
195	7	389.09	1.454	.0717	.00419
209	7	292.11	1.209	.0596	.00348
226	7	413.57	1.047	.0516	.00301
237	7	279.19	0.783	.0387	.00226
251	7	127.96	0.433	.0212	.00125

[1]Depth-day means include all plots (17) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 2

1972 SEASONAL SOIL BULK DENSITY MEANS BY DAY-DEPTH[1]
FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS

Julian days	Depth in cm	Bulk density
171	2	.191
181	2	.171
195	2	.267
209	2	.249
226	2	.245
237	2	.250
251	2	.194
171	7	.385
181	7	.414
195	7	.507
209	7	.512
226	7	.499
237	7	.513
251	7	.431

[1]Depth-day means include all plots (17) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 3

1972 SEASONAL SOIL MOISTURE (WET AND DRY WT. %) MEANS BY DAY-DEPTH[1] FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS

Julian days	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
171	2	.826	6.419
181	2	.785	5.155
195	2	.698	2.978
209	2	.705	3.077
226	2	.728	3.894
237	2	.732	3.619
251	2	.768	4.624
171	7	.740	4.072
181	7	.639	2.801
195	7	.487	1.179
209	7	.495	1.156
226	7	.507	1.368
237	7	.518	1.609
251	7	.526	1.406

[1]Dapth-day means include all plots (17) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 4

1973 SEASONAL MYCELIUM MEANS BY DAY-DEPTH[1]

FOR A 1CM WAFER TO A 7CM DEPTH

Julian day	Depth in cm	Mycelium			
		meters/g soil	g/m ^{2}	g C/m^2	g N/m^2
179	1	1544.87	1.529	.0753	.00440
209	1	757.57	0.915	.0451	.00264
234	1	888.13	1.288	.0634	.00371
166	2	346.05	1.160	.0572	.00334
169	2	804.09	1.523	.0750	.00439
179	2	1446.86	1.647	.0810	.00474
189	2	932.15	1.313	.0647	.00378
199	2	563/3;	0.878	.0433	.00253
209	2	579.75	0.913	.0450	.00263
219	2	949.11	1.616	.0796	.00466
229	2	814.41	1.310	.0646	.00378
234	2	747.35	1.416	.0698	.00408
249	2	882.03	0.969	.0477	.00279
267	2	739.21	0.694	.0342	.00200
179	3	1252.82	1.671	.0823	.00481
209	4	367.01	.805	.0396	.00230
234	4	434.62	1.227	.0604	.00350
179	5	559.44	1.013	.0498	.00290
209	3	417.30	0.801	.0394	.00231
234	3	557.45	1.473	.0726	.00424
179	4	1096.48	1.585	.0781	.00456
209	5	270.73	0.691	.0341	.00199
234	5	252.27	0.976	.0481	.00281
179	6	346.20	0.771	.0380	.00222
209	6	279.15	0.809	.0399	.00233
234	6	284.95	1.091	.0538	.00314

[1]Depth-day means include all plots (24) on U.S. IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 4 Continued

Julian day	Depth in cm	Mycelium			
		meters/g soil	g/m^2	g C/m^2	g N/m^2
166	7	210.35	0.851	.0419	.00245
169	7	468.33	1.107	.0545	.00319
179	7	266.91	0.762	.0375	.00219
189	7	384.61	0.830	.0409	.00239
199	7	232.58	0.859	.0423	.00247
209	7	158.76	0.608	.0299	.00175
219	7	230.56	0.632	.0311	.00182
229	7	297.88	1.045	.0515	.00301
234	7	212.10	0.830	.0409	.00239
249	7	231.12	0.455	.0224	.00131
267	7	521.52	1.077	.0531	.00310

TABLE 5

1973 SEASONAL SOIL BULK DENSITY MEANS BY DAY-DEPTH[1]
FOR A 1CM WAFER $1m^2$ TO A DEPTH OF 7CM

Julian[2] days	Depth[3] in cm	Bulk density
179	1	.146
209	1	.159
234	1	.211
166	2	.587
169	2	.342
179	2	.209
189	2	.234
199	2	.228
209	2	.202
219	2	.253
229	2	.261
234	2	.277
249	2	.139
267	2	.133
179	3	.244
209	3	.291
234	3	.367
179	4	.280
209	4	.382
234	4	.418
179	5	.337
209	5	.449
234	5	.498
179	6	.379
209	6	.562
234	6	.583

[1]Depth-day means include all plots (24) on US IBP TB Site moisture gradient, Barrow, Alaska.

[2]Julian day 179 is June 28.

[3]Depth 1=0-1cm, 2=1-2cm, etc.

TABLE 5 Continued

Julian days	Depth in cm	Bulk density
166	7	.710
169	7	.617
179	7	.460
189	7	.502
199	7	.517
209	7	.624
219	7	.456
229	7	.570
234	7	.621
249	7	.352
267	7	.350

TABLE 6

1973 SEASONAL SOIL MOISTURE MEANS BY DAY-DEPTH[1]

FOR A 1CM WAFER $1m^2$ TO A 7CM DEPTH

Julian[2] days	Depth[3] in cm	Soil moisture	
		Wet wt.	Dry wt.
179	1	.830	6.237
209	1	.801	4.777
234	1	.787	4.482
166	2	.302	0.457
169	2	.594	1.851
179	2	.800	5.558
189	2	.782	4.921
199	2	.778	4.551
209	2	.779	4.205
219	2	.733	4.119
229	2	.770	4.722
234	2	.749	3.967
249	2	.815	5.095
267	2	.813	4.788
179	3	.774	4.722
209	3	.713	3.576
234	3	.700	3.469
179	4	.749	4.129
209	4	.662	3.072
234	4	.661	3.022
179	5	.709	3.538
209	5	.626	2.473
234	5	.615	2.360
179	6	.668	2.781
209	6	.558	1.805

[1]Depth-day mean include all plots (24) on US IBP TB Site moisture gradient, Barrow, Alaska.

[2]Julian day 179 is June 28.

[3]Depth 1=0-1cm, 2=1-2cm, etc.

TABLE 6 Continued

Julian days	Depth in cm	Soil Moisture	
		Wet wt.	Dry wt.
234	7	.558	1.732
166	7	.155	0.192
169	7	.352	0.893
179	7	.626	2.149
189	7	.644	2.581
199	7	.604	2.111
209	7	.521	1.577
219	7	.588	1.946
229	7	.573	1.883
234	7	.533	1.433
249	7	.641	2.498
267	7	.639	2.351

TABLE 7

1974 SEASONAL MYCELIUM MEANS BY DAY-DEPTH[1]
FOR A 1CM WAFER $1m^2$ AT 1-2CM AND 6-7CM DEPTHS

Julian day	Depth in cm	Mycelium	
		Meters/g soil	g/m^2
231	2	2417.0	3.720
241	2	871.5	1.847
251	2	1762.4	3.246
261	2	982.1	3.039
271	2	1824.1	2.363
231	7	256.6	1.775
241	7	203.2	1.334
251	7	179.5	.696
261	7	155.0	.791
271	7	177.8	.636

[1]Depth-day means include all plots (17) on the US IBP TB Site moisture gradient, Barrow, Alaska.

TABLE 8

1974 SEASONAL BULK DENSITY MEANS BY DAY-DEPTH[1]
FOR A 1CM WAFER $1m^2$ AT 1-2CM and 6-7CM DEPTHS

Julian day	Depth in cm	Bulk density
231	2	.182
241	2	.433
251	2	.357
261	2	.568
271	2	.190
231	7	.857
241	7	.800
251	7	.631
261	7	.682
271	7	.516

[1]On US IBP TB Sites Barrow, Alaska.

TABLE 9

1974 SEASONAL SOIL MOISTURE (WET AND DRY WT %) MEANS
BY DAY-DEPTH FOR A 1CM WAFER AT 1-2CM AND 6CM DEPTHS

Julian day	Depth in cm	Soil Moisture	
		Wet wt. %	Dry wt. %
231	2	77.5	423.2
241	2	61.2	243.9
251	2	67.6	369.8
261	2	60.8	264.7
271	2	82.8	483.7
231	7	41.7	97.9
241	7	43.2	92.9
251	7	54.8	178.5
261	7	48.2	106.4
271	7	51.6	122.0

APPENDIX 6

TABLE 1

1974 MYCELIUM MEANS BY PLOT-DAY[1]

Plot	Julian day	Mycelium	
		meters/g soil	g/m^2
416	231	1991.9	3.584
	241	1107.8	2.167
	251	1358.1	2.063
	261	862.4	1.445
	271	2693.5	3.100
424	231	1027.3	3.807
	241	221.5	.573
	251	798.3	1.083
	261	489.6	.646
426	231	2483.8	5.941
	241	900.7	1.988
	251	1833.1	4.732
	261	850.1	3.611
428	231	503.0	.688
	241	305.0	.591
	251	756.4	1.085
	261	397.6	.704
	271	954.8	1.626
1233	231	176.3	.311
	241	136.8	.418
	251	108.8	.891
	261	237.8	2.275

[1]On US IBP Tundra Biome Sites, Barrow, Alaska.

TABLE 2

1974 SOIL BULK DENSITY (g/cc) MEANS BY PLOT-DAY[1]

Plot	Julian day	Soil Bulk density
416	231	.518
	241	.338
	251	.510
	261	.301
	271	.153
424	231	.829
	241	.702
	251	.238
	261	.387
426	231	.466
	241	.322
	251	.388
	261	.702
428	231	.255
	241	.366
	251	.237
	261	.271
	271	.227
1233	231	.499
	241	.463
	251	1.100
	261	1.273

[1]On US IBP Tundra Biome Sites, Barrow, Alaska.

TABLE 3

1974 SOIL MOISTURE (WET AND DRY WT. %) MEANS BY PLOT-DAY[1]

Plot	Julian day	Soil Moisture	
		Wet wt. %	Dry wt. %
416	231	65.2	271.7
	241	70.0	264.9
	251	63.9	256.9
	261	70.6	269.3
	271	83.7	514.0
424	231	53.5	224.6
	241	53.0	166.1
	251	81.7	489.5
	261	66.5	306.8
426	231	64.0	218.0
	241	68.5	232.5
	251	67.9	219.7
	261	46.4	97.2
428	231	78.6	421.2
	241	67.8	235.8
	251	78.7	388.3
	261	75.0	305.7
	271	81.9	453.4
1233	231	34.9	73.4
	241	33.6	62.5
	251	14.1	16.3
	261	19.6	25.6

[1]On US IBP Tundra Biome Sites, Barrow, Alaska.

APPENDIX 7

TABLE 1

METERS OF MYCELIUM/g DRY WT. SOIL MEANS BY HABITAT ON US IBP TB SITES, BARROW, ALASKA.

A. Overall Seasonal Means[1]

1972	1973	1974
747.4	587.2	803.1

B. Means By Habitat[2]

Habitat	1972	1973	1974
Meadow	938.0	537.6	1414.3
Trough	573.5	311.0	600.9
Rim	880.1	957.7	1439.9
Basin	575.4	382.4	454.9
Top	308.3	271.4	153.2

C. Means By Depths[3]

Habitat	Depth	1972	1973	1974
Meadow	1-2cm	1507.1	213.1	3268.7
Trough		753.2	380.4	1600.3
Rim		1344.8	1290.7	3503.9
Basin		892.0	580.0	922.7
Top		368.9	396.2	231.8
Meadow	6-7cm	344.2	217.5	131.5
Trough		382.6	263.9	229.9
Rim		427.9	439.2	444.9
Basin		258.9	143.7	174.4
Top		247.7	177.7	75.8

[1]All plots depths and days in the habitat.

[2]All plots and depths in the habitat.

[3]All plots in the habitat.

TABLE 1 Continued

D. Means By Sample (Julian) Day[4]

Day	Meadow	Trough	Rim	Basin	Top
			1972		
171	1383.5	976.4	1428.3	984.4	F
181	1454.5	1703.9	96.4	1076.8	526.1
195	808.6	624.2	611.4	612.7	317.1
209	884.8	579.4	779.2	610.5	414.5
226	954.8	595.1	1277.8	531.3	159.6
237	790.5	221.8	1119.3	279.1	235.0
251	493.2	268.6	462.4	201.6	304.5
			1973		
166	232.3	F	642.6	F	109.5
169	915.6	356.2	1134.1	663.9	419.5
179	895.7	370.6	1710.7	428.4	333.7
189	590.2	783.0	857.0	420.9	291.1
199	492.7	170.1	639.9	409.6	229.9
209	371.4	191.6	633.8	304.6	236.5
219	403.8	421.6	890.2	496.3	232.8
229	457.4	432.7	873.6	323.0	313.2
234	472.2	246.7	776.4	334.2	197.3
249	466.6	214.5	995.0	409.0	255.9
267	281.5	434.2	807.6	421.4	897.6
			1974		
231	1991.9	1027.3	2483.8	503.0	174.5
241	1107.8	221.5	900.7	305.0	136.8
251	1358.1	798.3	1833.1	756.4	108.8
261	862.4	489.6	850.1	397.6	237.8
271	2693.5	F	F	954.8	F

[1]All plots and depths in the habitat.

TABLE 1 Continued

E. Means By Day[5] At 1-2cm Depth

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	1-2cm	1912.1	1087.3	1999.2	1237.6	F
181		2012.7	1918.0	96.4	1565.6	498.9
195		1501.7	457.3	904.6	1147.4	376.6
209		1418.8	988.5	1160.9	1038.3	587.9
226		1779.5	846.3	1900.4	682.5	156.2
237		1088.7	359.5	1764.9	450.3	448.4
251		841.6	506.7	842.0	372.2	52.0
			1973			
166	1-2cm	232.3	F	726.5	F	130.3
169		915.6	304.4	1320.2	663.9	597.7
179		1368.6	436.4	2700.0	427.5	576.2
189		929.1	685.2	1359.0	628.0	431.4
199		939.7	184.8	717.6	539.1	305.0
209		608.4	225.8	885.2	499.7	387.4
219		763.1	646.4	1538.8	936.9	203.3
229		818.4	483.7	1331.4	437.4	357.2
234		844.1	448.6	1177.8	465.1	218.2
249		676.9	310.3	1651.0	612.7	395.5
267		424.0	121.3	906.3	718.8	1476.6
			1974			
231	1-2cm	4512.0	1955.4	4436.5	872.5	308.7
241		1722.3	1209.8	2423.1	856.7	174.0
251		2635.3	1464.1	3320.2	1277.5	114.9
261		2340.6	896.3	840.5	343.3	389.9
271		2693.5	F	F	954.8	F

[5]All plots in the habitat.

TABLE 1 Continued

F. Means By Day[6] At 6-7cm Depth

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	6-7cm	590.5	754.5	857.4	731.3	F
181		896.3	1489.9	144.5	588.0	553.2
195		115.6	791.1	318.2	78.1	257.6
209		350.8	170.3	397.4	182.7	241.1
226		130.1	343.0	655.2	380.0	163.0
237		492.4	84.2	473.7	107.8	21.6
251		144.8	30.6	82.8	31.0	557.0
			1973			
166	6-7cm	F	F	474.6	F	78.2
169		F	511.5	761.9	F	153.2
179		228.6	110.4	462.4	198.6	138.9
189		251.3	880.8	354.9	213.8	150.9
199		45.8	143.6	484.4	98.5	154.8
209		91.4	86.1	274.2	73.9	169.0
219		44.5	196.7	421.7	55.8	262.2
229		96.3	381.7	415.7	208.5	269.3
234		82.7	43.1	442.7	108.8	198.0
249		256.2	118.8	339.0	205.2	114.7
267		139.0	747.1	208.9	124.0	318.6
			1974			
231	6-7cm	176.8	401.1	531.1	133.5	40.4
241		263.6	61.9	489.4	51.3	136.0
251		80.9	132.4	346.1	235.3	102.8
261		26.1	29.8	463.7	197.3	57.8

[6]All plots in the Habitat.

TABLE 2

GRAMS BELOWGROUND FUNGAL BIOMASS (DRY WT.)[1]/m^2 1CM DEEP MEANS BY HABITAT ON US IBP TB SITES, BARROW, ALASKA

A. Overall seasonal means[2]

1972	1973	1974
1.493	1.053	1.824

B. Means by habitat[3]

Habitat	1972	1973	1974
Meadow	1.390	.699	2.483
Trough	.990	.416	1.614
Rim	2.138	1.859	3.691
Basin	.826	.539	.740
Top	.995	.864	.758

C. Means by depths[4]

Habitat	Depth	1972	1973	1974
Meadow	1-2cm	2.000	.939	4.326
Trough		.749	.340	1.870
Rim		2.723	2.082	8.105
Basin		1.143	.744	1.314
Top		.886	1.003	1.052
Meadow	6-7cm	.758	.297	.862
Trough		1.243	.537	1.965
Rim		1.569	1.375	1.955
Basin		.509	.289	.423
Top		1.104	.753	.597

[1]Dry wt. equals 11.5% of fresh mycelium wt.

[2]All plots, depths and days in the habitat.

[3]All plots and depths in the habitat.

[4]All plots in the habitat.

TABLE 2 Continued

D. Means by sample (Julian) day[5]

Day	Meadow	Trough	Rim	Basin	Top
			1972		
171	1.960	1.744	5.409	1.455	F
181	2.170	3.125	.478	1.528	1.633
195	1.190	1.510	1.825	.825	1.173
209	1.332	.817	2.186	.857	1.170
226	1.141	.958	2.341	.843	.679
237	1.421	.302	2.445	.395	.550
251	.830	.269	1.260	.263	1.174
			1973		
166	.904	F	1.648	F	.733
169	.861	.358	2.428	1.421	1.389
179	1.044	.444	2.282	.518	1.019
189	.724	.815	1.543	.671	1.017
199	.445	.254	1.582	.564	.691
209	.536	.310	1.258	.499	.888
219	.613	.679	2.087	.554	.721
229	.625	.782	2.065	.512	1.056
234	.662	.355	2.367	.522	.679
249	.533	.179	1.343	.453	.477
267	.241	.334	1.353	.389	.997
			1974		
231	3.584	3.807	5.941	.688	.311
241	2.167	.573	1.988	.591	.418
251	2.063	1.083	4.732	1.085	.891
261	1.445	.646	3.611	.704	2.275
271	3.100	F	F	1.626	F

[5]All plots and depths in the habitat.

TABLE 2 Continued

E. Means by day[6] at 1-2cm depth

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	1-2cm	2.461	1.406	6.565	1.553	F
181		2.542	1.614	.478	1.965	1.042
195		2.093	.461	2.099	1.489	1.015
209		1.929	1.004	2.299	1.338	1.269
226		2.033	1.778	3.170	.889	.557
237		1.503	.334	3.539	.578	1.012
251		1.338	.441	2.130	.467	.109
			1973			
166	1-2cm	.904	F	1.540	F	.993
169		.861	.287	2.706	1.421	1.910
179		1.583	.464	2.685	.472	1.693
189		1.026	.451	1.985	.940	1.305
199		.797	.164	1.411	.688	.761
209		.817	.233	1.457	.799	.886
219		1.131	.541	3.221	.997	.558
229		.905	.481	2.541	.579	.821
234		1.078	.435	2.847	.698	.518
249		.641	.201	1.937	.587	.598
267		.266	.075	1.011	.491	.979
			1974			
231	1-2cm	5.793	2.141	.275	1.023	.368
241		2.327	1.513	5.395	1.529	.813
251		3.618	1.861	8.315	1.633	.813
261		3.755	.914	3.919	.646	5.963
271		3.100	F	F	1.626	F

[6]All plots in the habitat.

TABLE 2 Continued

F. Means by day[7] 6-7cm depth

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	6-7cm	1.208	2.410	4.252	1.357	F
181		1.797	4.635	.717	1.091	2.224
195		.285	2.555	1.551	1.162	1.332
209		.735	.631	2.073	.376	1.070
226		.249	1.038	1.512	.798	.800
237		1.338	.270	1.352	.211	.087
251		.321	.098	.390	.058	2.239
			1973			
166	6-7cm	F	F	1.865	F	.344
169		F	.572	1.873	F	.609
179		.484	.274	1.468	.348	.548
189		.423	1.090	1.101	.402	.728
199		.094	.416	1.922	.275	.621
209		.410	.225	.975	.182	1.021
219		.094	.817	.952	.110	.884
229		.345	1.032	1.590	.445	1.291
234		.198	.264	1.791	.237	.855
249		.424	.157	.749	.319	.355
267		.215	.594	1.696	.287	1.015
			1974			
231	6-7cm	1.341	4.317	2.607	.354	.255
241		.979	.295	1.918	.112	.608
251		.509	.305	1.149	.537	.980
261		.114	.182	2.769	.510	.381

[7]All plots in the habitat.

TABLE 3

SOIL BULK DENSITY (g/cc) MEANS BY HABITAT ON US IBP TB SITES, BARROW, ALASKA

A. Overall seasonal means[1]

1972	1973	1974
.358	.359	.493

B. Means by habitat[2]

Habitat	1972	1973	1974
Meadow	.225	.232	.416
Trough	.299	.263	.607
Rim	.443	.433	.425
Basin	.216	.219	.304
Top	.623	.612	.716

C. Means by depths[3]

Habitat	Depth	1972	1973	1974
Meadow	1-2cm	.150	.153	.178
Trough		.142	.127	.156
Rim		.284	.275	.331
Basin		.171	.181	.181
Top		.470	.472	.641
Meadow	6-7cm	.303	.382	.859
Trough		.465	.407	.845
Rim		.599	.622	.566
Basin		.261	.281	.327
Top		.776	.739	1.001

[1]All plots, depths and days in the habitat.

[2]All plots and depths in the habitat.

[3]All plots in the habitat.

TABLE 3 Continued

D. Means by sample (Julian) day.[4]

Day	Meadow	Trough	Rim	Basin	Top
			1972		
171	.202	.248	.549	.207	F
181	.216	.263	.485	.207	.407
195	.257	.306	.467	.219	.678
209	.216	.306	.432	.219	.678
226	.216	.306	.405	.219	.678
237	.216	.306	.432	.219	.678
251	.216	.306	.473	.207	.407
			1973		
166	.518	F	.341	F	.823
169	.128	.145	.351	.285	.914
179	.177	.232	.289	.190	.633
189	.177	.209	.498	.229	.628
199	.233	.224	.471	.224	.418
209	.261	.297	.479	.239	.561
219	.260	.293	.414	.225	.583
229	.409	.241	.532	.234	.590
234	.228	.349	.544	.228	.699
249	.180	.198	.306	.171	.345
267	.157	.089	.316	.209	.256
			1974		
231	.518	.829	.466	.255	.499
241	.338	.702	.322	.366	.463
251	.510	.238	.388	.237	1.100
261	.301	.387	.702	.271	1.272
271	.153	F	F	.227	F

[4] All plots and depths in the habitat.

TABLE 3 Continued

E. Means by day at 1-2cm depth[5]

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	1-2cm	.139	.158	.437	.167	F
181		.139	.112	.220	.167	.278
195		.182	.141	.316	.173	.519
209		.139	.141	.265	.173	.519
226		.139	.141	.254	.173	.519
237		.139	.141	.265	.173	.519
251		.139	.141	.329	.167	.278
			1973			
166	1-2cm	.518	F	.250	F	.835
169		.128	.144	.318	.285	.822
179		.142	.136	.149	.152	.612
189		.128	.127	.306	.196	.366
199		.133	.131	.318	.178	.306
209		.153	.133	.245	.210	.282
219		.200	.111	.332	.171	.447
229		.137	.126	.380	.182	.451
234		.164	.171	.352	.205	.511
249		.130	.086	.150	.130	.218
267		.087	.083	.171	.119	.088
			1974			
231	1-2cm	.171	.146	.278	.156	.159
241		.180	.166	.296	.238	.622
251		.183	.169	.333	.170	.930
261		.213	.136	.621	.251	1.620
271		.153	F	F	.227	F

[5]All plots in the habitat.

TABLE 3 Continued

F. Means by day at 6-7cm depth[6]

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	6-7cm	.297	.427	.660	.247	F
181		.293	.414	.618	.247	.535
195		.331	.471	.618	.266	.837
209		.293	.471	.600	.266	.837
226		.293	.471	.557	.266	.837
237		.293	.471	.600	.266	.837
251		.293	.471	.618	.247	.535
			1973			
166	6-7cm	F	F	.523	F	.805
169		F	.149	.417	F	1.051
179		.301	.350	.588	.239	.741
189		.227	.291	.689	.263	.889
199		.332	.391	.776	.333	.530
209		.581	.439	.811	.322	.806
219		.320	.474	.496	.279	.719
229		.681	.356	.684	.286	.728
234		.401	.787	.673	.307	.883
249		.231	.310	.463	.211	.471
267		.227	.095	.462	.299	.424
			1974			
231	6-7cm	1.009	1.432	.653	.353	.838
241		.494	.633	.522	.291	.594
251		.837	.306	.442	.304	1.269
261		.582	.813	.794	.344	.878

[6]All plots in the habitat.

TABLE 4

SOIL MOISTURE (DRY WT. %) MEANS BY HABITAT ON US IBP TB SITES, BARROW, ALASKA

A. Overall seasonal means[1]

1972	1973	1974
274.1	334.7	223.3

B. Means by habitat[2]

Habitat	1972	1973	1974
Meadow	403.4	445.3	270.8
Trough	426.0	480.6	264.1
Rim	167.0	262.4	206.0
Basin	282.6	375.2	314.4
Top	85.6	127.8	50.0

C. Means by cm depths[3]

Habitat	Depth	1972	1973	1974
Meadow	1-2cm	545.1	548.0	465.4
Trough		642.9	668.4	579.4
Rim		247.5	345.3	284.1
Basin		344.1	432.1	501.8
Top		101.6	174.2	65.1
Meadow	6-7cm	255.6	262.2	88.0
Trough		196.3	275.1	171.7
Rim		88.6	132.3	130.6
Basin		221.2	287.4	266.4
Top		69.6	88.6	19.3

[1]All plots, depths and days in the habitat.

[2]All plots and depths in the habitat.

[3]All plots in the habitat.

TABLE 4 Continued

D. Means by sample (Julian) day[4]

Day	Meadow	Trough	Rim	Basin	Top
			1972		
171	628.2	744.0	88.4	489.8	F
181	539.2	679.2	112.8	367.3	91.7
195	216.1	406.1	154.4	277.5	72.3
209	323.5	264.0	177.6	240.4	96.0
226	396.1	472.7	193.9	266.7	73.1
237	440.5	474.2	167.7	266.5	82.3
251	505.3	269.7	161.9	249.6	117.0
			1973		
166	70.0	F	40.7	F	27.9
169	264.2	269.1	101.9	236.9	44.2
179	512.9	547.6	403.4	446.9	130.8
189	533.2	607.8	254.3	393.3	161.9
199	444.0	592.6	247.9	373.6	141.6
209	443.3	422.2	233.0	329.8	118.2
219	402.7	399.9	219.4	390.6	111.1
229	380.2	509.9	231.4	410.5	131.2
234	426.5	394.8	206.9	348.1	122.5
249	460.2	546.9	294.6	382.9	190.7
267	413.6	620.3	262.4	338.0	416.0
			1974		
231	271.7	224.6	218.0	421.2	73.4
241	264.9	166.1	232.5	235.8	62.5
251	256.9	489.5	219.7	388.3	16.3
261	269.3	306.8	97.2	305.7	25.6
271	514.0	F	F	453.4	F

[4]All plots and depth in the habitat.

TABLE 4 Continued

E. Means by day at 1-2cm depth[5]

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	1-2cm	692.5	847.1	109.2	612.3	F
181		662.0	872.8	240.7	412.3	97.0
195		346.4	567.7	228.5	276.0	87.1
209		450.2	440.5	272.6	277.5	128.0
226		560.1	811.2	273.2	336.7	76.1
237		556.0	700.3	239.1	330.1	112.8
251		746.9	482.2	253.1	319.5	110.8
			1973			
166	1-2cm	70.0	F	52.0	F	33.3
169		264.2	264.9	136.3	236.9	56.6
179		641.2	704.3	591.5	548.5	156.3
189		688.0	784.8	366.7	460.3	214.3
199		558.6	758.5	316.1	423.7	187.3
209		568.9	584.8	338.9	345.7	191.8
219		530.0	668.3	262.1	464.0	135.2
229		618.5	724.1	323.9	508.6	167.8
234		522.5	555.3	309.5	386.6	165.5
249		571.3	762.9	420.2	467.4	264.6
267		540.7	678.8	391.3	422.2	681.0
			1974			
231	1-2cm	516.2	546.2	331.1	590.6	132.1
241		472.8	454.7	292.5	363.5	17.7
251		426.3	649.1	272.9	483.7	16.8
261		351.2	521.6	96.6	353.3	19.0
271		514.0	F	F	453.4	F

[5]All plots in the habitat.

TABLE 4 Continued

F. Means by day at 6-7cm depth[6]

Day	Depth	Meadow	Trough	Rim	Basin	Top
			1972			
171	6-7cm	531.7	537.8	67.5	367.3	F
181		416.4	485.5	48.8	322.3	86.3
195		85.8	244.4	80.3	179.0	57.5
209		196.7	87.4	82.6	203.3	64.0
226		232.1	134.2	114.5	196.8	70.0
237		325.0	248.0	96.3	202.9	51.9
251		263.6	57.1	70.7	179.6	123.2
			1973			
166	6-7cm	F	F	18.0	F	19.7
169		F	281.5	57.1	F	25.5
179		261.7	284.9	145.8	332.6	102.6
189		378.4	430.8	141.9	326.3	109.5
199		329.4	293.8	111.6	256.7	95.9
209		162.6	272.7	88.0	225.7	75.9
219		277.4	131.4	176.7	317.3	87.0
229		142.0	295.7	138.9	312.3	94.7
234		210.1	78.2	120.4	252.1	92.7
249		349.0	330.8	169.0	298.4	116.8
267		286.6	561.8	133.6	253.7	152.5
			1974			
231	6-7cm	74.2	44.0	104.8	251.7	14.7
241		154.7	118.6	126.9	246.6	22.7
251		87.5	329.9	166.4	292.9	15.8
261		92.6	72.6	83.7	226.7	56.2

[6]All plots in the habitat.

APPENDIX 8

TABLE 1

1974 VARIABLE PROFILE OVERALL MEANS IN A 1CM WAFER
1m ^{2} TO DEPTH OF THAW BY DEPTH[1]

Profile depth[2] in cm	Fungi		Soil	
	m Mycelium/gdws	g Mycelia/m ^{2}	Bulk Density	Soil Moisture (dry wt. %)
1	1761.6	2.55	.223	373.4
2	871.5	1.85	.433	243.9
3	1324.5	2.36	.351	297.1
4	1089.0	2.23	.396	267.7
5	994.1	2.21	.509	200.6
6	310.8	.96	.543	162.4
7	203.2	1.33	.800	92.9
8	177.8	.64	.516	122.0
9	227.6	.68	.508	125.2
10	159.7	.45	.531	123.7
11	285.8	.75	.551	134.2
12	259.5	1.34	.727	106.9
13	200.6	.59	.578	122.4
14	212.3	.55	.576	133.7
15	260.1	.62	.408	169.3
16	307.6	.74	.389	175.1
17	391.1	1.53	.495	146.5
18	337.2	.85	.327	188.3
19	190.2	.44	.309	222.5
20	125.3	.34	.566	123.3
21	285.4	.45	.208	226.3
22	392.5	.65	.244	244.3
23	277.5	1.15	.721	174.8

[1]All plots on JD day 241, August 29.

[2]1 = 0-1cm, etc.

APPENDIX 9

TABLE 1

1973 OVERALL MEAN BIOMASS (g/m^2) WITH DEPTH AND HABITAT[1]

Depth[2]	Meadows	Troughs	Rims	Basins	Tops
1	1.002	.455	2.053	1.033	.672
2	.939	.340	2.082	.744	1.003
3	1.058	.426	2.255	.495	1.155
4	.712	.438	2.251	.448	.856
5	.456	.222	1.716	.280	.869
6	.369	.430	1.685	.432	.642
7	.297	.537	1.375	.289	.753

TABLE 2

1973 OVERALL MEAN METERS OF MYCELIUM/G DRY WT. SOIL BY DEPTH AND HABITAT

Depth	Meadows	Troughs	Rims	Basins	Tops
1	993.5	540.7	1692.1	877.7	363.8
2	824.3	380.4	1290.7	580.0	396.2
3	888.4	329.1	1191.5	312.3	332.3
4	554.6	297.3	1118.7	310.3	210.5
5	344.8	121.7	628.2	178.2	178.3
6	207.4	154.7	524.3	220.5	143.5
7	132.1	263.9	439.2	143.7	177.7

[1]On US IBP Tundra Biome Sites, Barrow, Alaska.

[2]Depth 1=0-1cm.

TABLE 3

1973 SEASONAL SOIL MOISTURE (DRY WT. %) MEANS BY DEPTH AND HABITAT[1]

Depth[2]	Meadows	Troughs	Rims	Basins	Tops
1	615.5	738.2	479.5	486.9	217.7
2	548.0	668.4	345.3	432.1	174.2
3	575.7	530.6	328.5	406.5	188.9
4	526.9	466.2	261.8	383.5	93.3
5	431.8	392.6	188.4	339.0	87.6
6	310.3	241.6	147.9	311.9	87.7
7	262.2	275.1	132.3	287.4	88.5

TABLE 4

1973 OVERALL MEANS SOIL BULK DENSITY (g/cc) WITH DEPTH IN SPECIFIC HABITATS ON US IBP TUNDRA BIOME SITES, BARROW, ALASKA

Depth	Meadows	Troughs	Rims	Basins	Tops
1	.133	.122	.189	.133	.246
2	.153	.127	.275	.181	.472
3	.148	.204	.349	.207	.600
4	.167	.270	.419	.201	.737
5	.185	.321	.560	.216	.778
6	.313	.439	.643	.259	.776
7	.382	.407	.622	.281	.739

[1]On US IBP TB Sites Barrow, Alaska.

[2]Depth 1=0-1cm.

TABLE 5

1974 MYCELIUM PROFILE MEANS IN A 1CM WAFER 1m ^{2} TO DEPTH OF THAW BY HABITAT ON DAY 241[1]

Profile depth[2] in cm	m Mycelium/g dry soil				
	Meadow	Trough	Rim	Basin	Top
1	1894.2	664.2	2908.9	1414.7	491.4
2	3268.7	1600.3	3503.9	992.7	231.8
3	2229.8	945.2	1617.6	261.4	92.8
4	1442.9	527.9	1347.2	347.3	89.6
5	2090.7	156.6	632.7	368.8	71.3
6	985.5	541.8	485.5	348.9	45.1
7	131.5	229.9	444.9	174.4	75.8
8	139.5	134.4	488.6	89.0	37.6
9	218.5	147.4	703.3	12.6	56.4
10	319.4	2.0	325.7	27.4	123.9
11	534.8	84.3	597.5	50.6	161.8
12	589.9	31.8	343.8	138.0	69.0
13	529.1	0.0	153.8	163.2	157.0
14	609.4	11.6	327.8	97.4	15.5
15	336.2	120.6	531.2	152.9	159.5
16	519.2	106.2	496.6	163.9	252.1
17	1223.8	106.3	267.5	122.4	137.1
18	825.5	77.2	407.1	244.8	131.3
19	F	72.3	220.1	266.5	201.8
20	F	10.9	F	194.6	170.4
21	F	F	F	286.5	284.3
22	F	F	F	504.8	280.1
23	F	F	F	366.2	F
24	F	F	F	292.7	F

[1] August 29.

[2] 1 = 0-1cm, etc.

TABLE 6

1974 MYCELIUM (g/m ^{2}) PROFILE MEANS IN A 1CM WAFER 1m ^{2} TO DEPTH OF THAW BY HABITAT ON DAY 241[1]

Profile depth[2] in cm	g Mycelium/m ^{2}				
	Meadow	Trough	Rim	Basin	Top
1	2.58	0.72	4.75	1.83	3.41
2	4.33	1.87	8.11	1.31	1.05
3	3.28	1.19	4.30	0.51	0.91
4	2.35	0.93	4.60	0.66	0.75
5	4.03	0.87	3.31	0.61	0.59
6	2.76	3.69	2.36	0.61	0.31
7	0.86	1.97	1.96	0.42	0.60
8	0.58	0.56	1.57	0.29	0.17
9	0.98	0.59	1.60	0.06	0.19
10	0.98	0.59	1.60	0.06	0.32
11	1.11	0.86	1.22	0.23	0.31
12	1.55	0.32	1.20	0.50	0.13
13	1.32	0.00	0.63	0.63	0.35
14	1.33	0.12	0.87	0.39	0.03
15	0.63	0.75	0.86	0.44	0.43
16	1.32	0.49	0.61	0.57	0.70
17	4.02	0.47	0.33	0.44	0.35
18	2.40	0.18	0.47	0.91	0.28
19	F	0.19	0.28	0.79	0.50
20	F	0.08	F	0.55	0.40
21	F	F	F	0.33	0.56
22	F	F	F	0.60	0.70
23	F	F	F	0.51	F
24	F	F	F	0.51	F

[1]August 29.

[2]1 = 0-1cm, etc.

TABLE 7

1974 SOIL PROFILE BULK DENSITY MEANS IN A 1CM WAFER
1m ^{2} TO DEPTH OF THAW BY HABITAT ON DAY 241[1]

Profile depth[2] in cm	Bulk density				
	Meadow	Trough	Rim	Basin	Top
1	.185	.141	.217	.172	.735
2	.178	.156	.331	.181	.641
3	.199	.176	.511	.264	1.135
4	.230	.241	.637	.254	1.069
5	.273	.621	.627	.244	1.223
6	.370	.884	.633	.245	.986
7	.859	.845	.566	.327	1.001
8	.557	.556	.428	.431	.608
9	.594	.536	.320	.662	.448
10	.409	.905	.325	.675	.343
11	.277	1.360	.271	.593	.256
12	.349	1.329	.463	.485	.242
13	.333	1.198	.544	.516	.300
14	.289	1.408	.353	.537	.294
15	.248	.832	.216	.381	.361
16	.338	.614	.164	.460	.368
17	.437	.582	.165	.473	.340
18	.387	.317	.152	.496	.283
19	F	.348	.167	.394	.327
20	F	1.015	F	.375	.309
21	F	F	F	.154	.262
22	F	F	F	.157	.331
23	F	F	F	.186	F
24	F	F	F	.230	F

[1]August 29.

[2]1 = 0-1cm, etc.

TABLE 8

1974 SOIL PROFILE MOISTURE MEANS FOR A 1CM WAFER

$1m^2$ TO DEPTH OF THAW BY HABITAT ON DAY 241[1]

Profile depth[2] in cm	Soil moisture (dry wt.)				
	Meadow	Trough	Rim	Basin	Top
1	4.269	5.605	2.852	4.139	0.298
2	4.654	5.794	2.841	5.018	0.651
3	3.895	4.214	1.809	3.290	0.139
4	3.640	3.170	1.687	3.209	0.139
5	2.967	1.065	1.436	3.165	0.138
6	2.284	0.796	0.989	3.044	0.190
7	0.880	1.717	1.306	2.664	0.193
8	1.311	1.320	1.526	1.674	0.270
9	1.333	1.345	2.189	1.047	0.345
10	1.817	0.642	2.223	1.023	0.479
11	2.354	0.425	2.069	1.282	0.582
12	2.347	0.359	1.514	1.544	0.556
13	2.328	0.356	1.269	1.649	0.517
14	2.053	0.346	1.891	1.823	0.570
15	2.453	0.717	2.815	1.821	0.659
16	2.076	1.330	2.766	1.805	0.779
17	1.736	1.270	2.947	1.546	0.918
18	1.721	1.985	3.079	1.580	1.049
19	F	2.667	3.154	1.922	1.155
20	F	0.765	F	1.589	1.344
21	F	F	F	2.874	1.652
22	F	F	F	3.180	1.706
23	F	F	F	3.049	F
24	F	F	F	3.167	F

[1] August 29.

[2] 1 = 0-1cm, etc.

TABLE 9

1973 SOIL BULK DENSITY (g/cc) EARLY, MID AND LATE SEASON MEANS 0-7CM BY HABITAT[1]

Habitat	June 28 (179)	July 28 (209)	August 22 (234)
Meadow	.177	.261	.228
Trough	.232	.297	.349
Rim	.289	.479	.544
Basin	.190	.239	.228
Top	.633	.560	.699

TABLE 10

1973 SOIL MOISTURES (DRY WT. %) EARLY, MID AND LATE SEASON MEANS 0-7CM BY HABITAT[1]

Habitat	June 28 (179)	July 28 (209)	August 22 (234)
Meadow	512.9	443.3	426.5
Trough	547.6	422.2	394.8
Rim	403.4	233.0	206.9
Basin	446.9	329.8	348.1
Top	130.8	118.2	122.5

[1]On US IBP TB Sites, Barrow, Alaska.

APPENDIX 10

TABLE 1

1973 METERS OF MYCELIUM/g DRY WT. SOIL PROFILE MEANS BY HABITAT, DAY AND DEPTH ON US IBP TB SITES, BARROW, ALASKA.

Habitat	Julian day[1]	Soil depth (cm)						
		1	2	3	4	5	6	7
Meadow	179	1366.7	1368.6	1499.3	910.2	574.5	322.2	228.6
	209	727.5	608.4	518.6	279.1	252.9	132.3	91.4
	234	886.3	844.1	647.3	474.5	207.0	167.7	82.7
Trough	179	919.3	436.4	486.0	363.2	152.9	125.8	110.4
	209	275.3	225.9	189.4	222.1	106.5	254.1	86.1
	234	427.6	448.6	311.9	306.6	105.5	84.1	43.1
Rim	179	2480.7	2700.0	2130.6	2135.0	1049.1	644.9	462.4
	209	1215.6	885.2	611.8	588.7	437.0	423.9	274.2
	234	1379.9	1177.8	832.0	632.3	451.1	519.3	4442.7
Basin	179	1132.7	427.5	364.4	383.5	281.2	211.1	198.6
	209	836.4	499.7	149.6	203.6	136.5	232.3	73.9
	234	664.0	465.1	423.0	3344.0	116.7	218.0	108.8
Top	179	533.3	576.2	494.4	266.1	217.1	110.1	138.9
	209	140.6	387.4	335.1	249.9	204.3	169.2	169.0
	234	417.4	218.2	167.4	115.6	113.6	151.2	198.0

[1]Julian Day = June 28.

TABLE 2

1973 BELOWGROUND FUNGAL BIOMASS (g/m^2) PROFILE MEANS BY HABITAT DAY AND DEPTH ON US IBP SITES, BARROW, ALASKA

Habitat	Julian day[1]	Soil depth (cm)						
		1	2	3	4	5	6	7
Meadow	179	1.369	1.583	1.641	1.026	.717	.489	.484
	209	.709	.817	.690	.413	.342	.329	.410
	234	.928	1.078	.844	.699	.311	.288	.198
Trough	179	.689	.464	.652	.543	.248	.227	.274
	209	.235	.233	.310	.380	.226	.602	.225
	234	.432	.435	.314	.392	.193	.460	.264
Rim	179	2.416	2.685	2.681	1.325	1.917	1.565	1.468
	209	1.487	1.457	1.244	2.422	1.085	1.233	.975
	234	2.256	2.847	2.841	1.917	2.171	2.242	1.791
Basin	179	.947	.472	.549	.546	.422	.343	.348
	209	1.275	.779	.233	.268	.223	.535	.182
	234	.876	.698	.703	.530	.194	.418	.237
Top	179	1.067	1.693	1.502	.968	.908	.447	.548
	209	.211	.886	.987	1.044	1.196	.870	1.021
	234	.737	.518	.977	.557	.501	.609	.855

[1]Julian Day 179 = June 28.

TABLE 3

1973 SOIL BULK DENSITY (g / cc) PROFILE MEANS BY HABITAT, DAY AND DEPTH ON US IBP SITES, BARROW, ALASKA

Habitat	Julian day[1]	Soil depth (cm)						
		1	2	3	4	5	6	7
Meadow	179	.136	.142	.139	.141	.168	.212	.301
	209	.120	.152	.151	.181	.185	.412	.581
	234	.142	.164	.153	.189	.202	.315	.401
Trough	179	.093	.136	.199	.275	.274	.299	.350
	209	.116	.133	.228	.247	.380	.440	.439
	234	.157	.171	.183	.190	.31	.578	.787
Rim	179	.136	.149	.194	.219	.354	.445	.588
	209	.170	.245	.373	.472	.583	.701	.811
	234	.260	.352	.480	.567	.716	.760	.673
Basin	179	.115	.152	.194	.192	.201	.236	.239
	209	.213	.210	.209	.201	.224	.298	.322
	234	.184	.205	.220	.210	.224	.244	.307
Top	179	.285	.612	.629	.722	.741	.698	.741
	209	.181	.282	.425	.653	.758	.819	.806
	234	.272	.511	.744	.834	.835	.812	.883

[1]Julian Day 179 = June 28.

TABLE 4

1973 SOIL MOISTURE (DRY WT. %) PROFILE MEANS BY HABITAT, DAY AND DEPTH ON US IBP SITES, BARROW, ALASKA

Habitat	Julian day[1]	Soil depth (cm)						
		1	2	3	4	5	6	7
Meadow	179	655.6	641.2	628.3	579.1	481.9	342.6	261.7
	209	613.8	568.9	557.9	518.8	424.5	295.1	162.6
	234	577.0	522.5	540.8	482.8	389.1	293.3	210.1
Trough	179	890.8	704.3	58.0	510.6	506.0	356.4	284.9
	209	688.6	584.8	475.0	378.2	315.0	237.9	272.7
	234	635.3	555.3	536.7	509.9	356.6	130.6	78.2
Rim	179	624.9	591.5	470.0	398.5	285.0	233.6	145.8
	209	445.9	338.9	267.1	214.8	168.0	108.5	88.0
	234	367.6	309.5	242.3	171.9	124.1	112.3	120.3
Basin	179	647.7	548.5	445.2	401.0	389.7	363.5	332.6
	209	366.7	345.7	411.6	398.9	304.3	256.1	225.7
	234	445.4	386.6	362.9	350.6	323.0	316.2	252.1
Top	179	197.5	156.3	136.8	111.3	105.1	106.0	102.6
	209	210.7	191.8	121.3	85.2	75.0	67.3	75.9
	234	244.9	165.5	98.5	83.3	82.8	89.8	92.7

[1]Julian Day 179 = June 28.

APPENDIX 11

TABLE 1

C H N ANALYSES OF TUNDRA SOILS

Plot	Depth[1]	Date	C%[2]	N%	H%	Moisture %	C/N ratio
400	2	Ju 28 72	38.43	2.88	5.39	601	13.3
400	7	Ju 28 72	35.88	2.04	5.24	182	17.6
416	2	Ju 28 72	37.96	2.67	5.21	387	14.2
416	7	Ju 28 72	35.56	1.92	4.89	218	18.5
450	2	Ju 28 72	38.89	2.44	5.14	89	15.9
450	7	Ju 28 72	35.89	2.10	4.76	30	17.1

[1]Depth 2-1-2cm, 7 = 6-7cm.

[2]Percents are based on dry weight values.

TABLE 2

C H N ANALYSES OF TUNDRA SOILS

Plot	Depth[1]		Date	C%[2]	N%	H%	Moisture %	C/N ratio
200	2	J	28 73	40.38	2.08	4.66	442	19.4
200	7	J	28 73	21.14	1.17	2.74	286	18.1
400	2	J	28 73	18.47	0.99	2.33	442	18.7
400	7	J	28 73	9.83	0.57	1.44	286	17.3
416	2	J	28 73	43.91	3.07	4.94	466	14.3
416	7	J	28 73	21.65	1.35	2.9	305	16.0
418	2	J	28 73	40.18	2.00	4.86	692	20.1
418	7	J	28 73	13.53	.69	1.87	96	19.6
420	2	J	28 73	38.23	2.53	4.53	500	15.1
420	7	J	28 73	39.06	3.19	5.15	327	12.3
424	2	J	28 73	36.32	1.77	4.33	866	20.5
424	7	J	28 73	9.63	.44	1.40	426	21.9
426	2	J	28 73	30.64	3.03	3.64	430	10.1
426	7	J	28 73	27.13	2.27	3.41	258	12.0
428	2	J	28 73	41.75	2.39	4.76	659	17.5
428	7	J	28 73	45.95	2.58	1.21	372	17.8
440	2	J	28 73	37.31	1.79	4.78	937	20.8
440	7	J	28 73	42.90	2.72	5.48	445	15.8
441	2	J	28 73	38.74	2.44	5.38	349	15.9
441	7	J	28 73	12.85	.60	2.05	53	21.4
442	2	J	28 73	36.78	2.34	5.24	486	15.7
442	7	J	28 73	37.89	2.03	4.97	299	18.7
1232	2	J	28 73	32.39	1.71	4.12	166	18.9
1232	7	J	28 73	29.34	1.58	3.55	148	18.6

[1]Depth 2-1-2cm, 7 = 6-7cm.

[2]Percents are based on dry weight values.

TABLE 2 Continued

Plot	Depth	Date	C%	N%	H%	Moisture %	C/N ratio
1233	2	J 28 73	16.36	1.12	2.50	20	14.6
1233	7	J 28 73	3.69	0.24	0.67	12	15.4

TABLE 2 Continued

C H N ANALYSES OF TUNDRA SOILS

Plot	Depth[1]	Date	C%[2]	N%	H%	Moisture %	C/N ratio
200	2	Ju 28 73	37.45	2.21	4.68	366	17.0
200	7	Ju 28 73	9.90	.60	1.51	49	16.5
400	2	Ju 28 73	16.53	1.10	2.42	396	15.0
400	2	Ju 28 73	18.42	1.22	2.73	396	15.1
400	7	Ju 28 73	12.00	0.71	1.73	166	16.9
416	2	Ju 28 73	39.07	2.85	4.79	400	13.7
416	7	Ju 28 73	18.39	1.06	2.77	97	17.4
416	7	Ju 28 73	18.76	0.68	2.83	97	27.6
420	2	Ju 28 73	39.23	2.59	4.97	385	15.1
420	7	Ju 28 73	34.69	2.34	4.23	249	14.8
424	2	Ju 28 73	42.41	.79	5.22	927	53.7
424	7	Ju 28 73	38.59	2.36	4.90	201	16.4
426	2	Ju 28 73	8.95	.55	1.57	157	16.3
426	7	Ju 28 73	5.08	.31	.92	54	16.4
428	2	Ju 28 73	42.12	2.31	5.37	375	18.2
428	7	Ju 28 73	43.25	3.05	5.67	204	14.2
440	2	Ju 28 73	40.47	3.10	5.22	575	13.1
440	7	Ju 28 73	38.89	2.38	4.60	298	16.3
441	2	Ju 28 73	42.01	.84	5.23	234	16.9
441	7	Ju 28 73	19.28	2.48	2.80	79	23.0
442	2	Ju 28 73	39.66	2.56	5.20	277	15.5
442	7	Ju 28 73	34.09	1.70	4.48	224	20.1
1232	2	Ju 28 73	37.27	2.03	4.73	188	18.4
1232	7	Ju 28 73	24.99	1.51	3.70	111	16.6

[1]Depth 2-1-2cm, 7 = 6-7cm.

[2]Percents are based on dry weight values.

TABLE 2 Continued

Plot	Depth	Date	C%	N%	H%	Moisture %	C/N ratio
1233	2	Ju 28 73	14.40	0.90	1.59	121	16.0
1233	7	Ju 28 73	2.89	0.30	0.62	12	9.6

TABLE 2 Continued

C H N ANALYSES OF TUNDRA SOILS

Plot	Depth[1]	Date	C%[2]	N%	H%	Moisture %	C/N ratio
200	2	A 22 73	38.88	2.12	4.67	467	18.3
200	7	A 22 73	17.02	.98	2.12	94	17.4
400	2	A 22 73	12.19	0.63	2.08	173	19.4
400	7	A 22 73	12.05	0.58	1.92	68	20.8
416	2	A 22 73	40.54	2.48	4.96	405	16.4
416	7	A 22 73	36.76	1.30	5.05	272	28.3
418	2	A 22 73	42.13	2.33	5.17	620	18.1
418	7	A 22 73	17.07	--	2.29	74	--
420	2	A 22 73	38.70	2.28	4.71	430	17.0
420	7	A 22 73	36.34	1.67	4.77	173	21.8
424	2	A 22 73	39.78	2.17	4.91	684	18.3
424	7	A 22 73	7.75	.54	1.35	60	14.4
426	2	A 22 73	10.47	.76	1.48	65	13.8
426	7	A 22 73	7.32	.43	1.06	45	17.0
428	2	A 22 73	39.68	2.35	4.80	415	16.9
428	7	A 22 73	45.11	2.76	5.73	347	16.3
440	2	A 22 73	40.74	2.41	5.02	733	16.9
440	7	A 22 73	42.12	2.95	5.19	57	14.3
441	2	A 22 73	45.13	2.18	5.37	398	20.7
441	7	A 22 73	43.32	2.37	5.35	227	18.3
442	2	A 22 73	41.24	2.26	5.19	315	18.3
442	7	A 22 73	30.44	1.60	3.84	237	19.0
1232	2	A 22 73	38.80	2.01	5.17	219	19.3
1232	7	A 22 73	37.74	1.72	5.20	146	21.9

[1]Depth 2-1-2cm, 7 = 6-7cm.

[2]Percents are based on dry weight values.

TABLE 2 Continued

Plot	Depth	Date	C%	N%	H%	Moisture %	C/N ratio
1233	2	A 22 73	4.14	0.40	0.70	37	10.4
1233	7	A 22 73	2.09	0.27	0.45	12	7.7

TABLE 3

C H N ANALYSES OF TUNDRA SOILS

Plot	Depth[1]	Date	C%[2]	N%	H%	Moisture %	C/N ratio
416	2	S 18 74	40.16	2.71	4.88	351	14.8
416	7	S 18 74	13.32	.65	1.88	93	20.5
424	2	S 18 74	43.69	2.51	5.28	522	17.4
424	7	S 18 74	6.44	.73	1.06	73	8.8
426	2	S 18 74	9.80	.62	1.51	97	15.8
426	7	S 18 74	16.26	.92	2.16	84	17.7
428	2	S 18 74	44.34	2.92	5.02	335	15.2
428	7	S 18 74	36.96	2.21	4.54	227	16.7
1233	2	S 18 74	3.78	.95	.61	19	4.0
1233	7	S 18 74	21.04	1.99	2.75	56	10.6

[1]Depth 2-1-2cm, 7 = 6-7cm.

[2]Percents are based on dry weight values.

TABLE 4

C N Analyses of Fungal Tissues

Taxon[1]	OKM/GAL	Tissue[2]	C%	N%	C ratio
AGABIS	-	B	38.46	7.71	4.99
AMAINA	10202	H	46.92	2.63	17.84
CLIPOL	10350	B1	42.33	7.27	5.82
CLIPOL	10350	B2	44.48	6.04	7.36
CLIPOL	10350	B3	49.26	7.65	6.44
CLIPOL	10350	H	40.68	2.01	20.24
CLIPOL	10756	B	40.07	6.24	6.23
CLIPOL	10756	H	40.88	1.76	23.23
COPMAR	11034	B1	43.17	5.53	7.81
CORHUR	11603	B1	43.46	3.44	12.63
CORHUR	11877	B2	43.90	2.71	16.20
CORHUR	11877	B3	45.66	4.82	9.47
CORHUR	11877	B4	41.20	1.28	32.19
CORMUC	10291	H	52.44	1.57	33.40
CORMUC	11611	B1	44.30	2.10	21.10
CYSAMI	11671	B2	44.27	6.21	7.13
CYSAMI	11671	B3	40.91	6.88	5.95
GALSUB	10279	B	42.22	5.66	7.46
GALSUB	10279	B	42.50	5.94	7.16
GALSUB	10279	H	40.52	3.82	10.61
GALSUB	10750	H	50.28	6.48	7.76
HEBPUS	11605	B1	45.41	4.48	10.14
INODEC	10290	H	46.17	1.74	26.54

[1]The first 3 letters of the genus and species names.

[2]B Cap, Gills and Stipe
B1 Cap and Gills only
B2 Cap only
B3 Gills only
B4 Stipe only
H Fresh Hyphae grown in liquid culture
S Sclerotium Hyphae grown in situ

TABLE 4 Continued

Taxon	OKM/GAL	Tissue	C%	N%	CN/ratio
IACIAN	11946	B1	44.84	5.39	8.32
IACLAN	11602	B1	44.85	4.74	9.46
LACLAN	11945	B2	43.86	4.48	9.79
LACLAN	11945	B3	48.02	6.35	7.56
IACIAN	11945	B4	33.54	2.41	13.91
IEPLOB	11944	B	43.22	7.31	5.91
MYRSUL	10857	S	40.87	1.66	24.62
NAEUDU	10865	B	30.30	5.47	5.54
NAEUDU	10865	H	44.87	3.23	13.89
NAEUDU	11607	B1	44.98	5.01	8.98
OMPERI	11623	B1	43.71	5.75	7.60
OMPHUD	11618	B1	45.15	5.73	7.88
OMPHUD	11859	B1	65.82	7.25	9.08
OMPLUT	11615	B1	40.55	6.01	6.75
OMPPYX	11635	B1	41.46	8.49	4.88
PANACC	10361	B	40.30	6.97	5.78
PANACC	10361	B	40.59	6.88	5.90
PANACC	10361	H	50.92	2.80	18.19
RUSEME	10869	B	43.18	3.90	1..07
RUSEME	10869	B	43.44	3.77	11.52
RUSEME	10869	H	48.00	1.69	28.40
RUSEME	10869	H	49.22	2.49	19.77

APPENDIX 12

FUNGAL BIOMASS DATA REDUCTION PROGRAM

```
// JOB
/*MAIN TIME=(15,30) ,REGION=(150,200) ,LINES=20
/*SETUP UNIT=SYSDA,ID=(USR304)
//STEP1 EXEC PL1LFCG
//PL1L.SYSIN DD *
 MAIN:PROC OPTIONS(MAIN);
 DCL(IMEAN,IS)CHAR(12);DCL G(50)CHAR(12);DCL WORK CHAR(624);
      ON ENDFILE(SYSIN) GO TO IT;
 DCL CHEC1 CHAR(80);
 DCL CHECK CHAR(80);
 DCL S(50)DEC FLOAT;
 CHEC1-'AS';
    R:S=0;
 GET EDIT(CHECK)(COL(1),A(80))
 IF CHECK ='FINISH FINISH' THEN CHEC1 = 'FINISH FINISH';
 GET EDIT((S(I)DO I=1 TO 50))(COL(1),F(4),14 F(5),F(6),
 F(4),14 F(5),F(6),F(4),14 F(5),3 F(1));
 DO M=1 To 50;DO N=1 TO 49;                          IF S(N)<S(N+1)
                                                     THEN DO; J=S(N);
                                                              S(N)=S(N+1);
                                                              S(N+1)=J;
                                                          END;
                                                     END;
                                        END;
 AMEAN=SUM(S)/50; SD=SQRT((SUM(S**2)-SUM(S)**2/50)/49);
 IMEAN=AMEAN;G=S;IS=SD;
 WORK-IMEAN11IS11G(1)11G(2)11G(3)11G(4)11G(5)11G(6)11G(7)11G(8)11
 G(9)11G(10)11G(11)11G(12)11G(13)11G(14)11G(15)11G(16)11G(17)11G(18)11
 G(19)11G(20)11G(21)11G(22)11G(23)11G(24)11G(25)11G(26)11G(27)11G(28)11
 G(29)11G(30)11G(31)11G(32)11G(33)11G(34)11G(35)11G(36)11G(37)11G(38)11
 G(39)11G(40)11G(41)11G(42)11G(43)11G(44)11G(45)11G(46)11G(47)11G(48)11
 G(49)11G(50);
 IF CHEC1 ='FINISH FINISH' THEN
 WRITE FILE(CL) FROM(work);
 ELSE WRITE FILE(UC)FROM(WORK);
      GOTO R;
 IT:
 END MAIN;
/*
//GO.UC DD UNIT=SYSDA,DISP=(NEW,PASS),
// DCB=(RECFM=F,LRECL=624,BLKSIZE=624), SPACE=(2048,(425,106)),
// DSN=&&TEMP1
//GO.CL DD UNIT=SYSDA,DISP=(NEW,PASS),
// DCB=(RECFM=F,LRECL=624,BLKSIZE=624), SPACE=(2048,(425,106)),
// DSN=&&TEMP2
//GO.SYSIN DD *
      -UNCLAMPED DATA CARDS-
FINISH FINISH
      -CLAMPED DATA CARDS-
```

```
/*
//STEP2 EXEC SAS
//SAS.TRANS74 DD UNIT=SYSDA,DISP=(NEW,KEEP),VOL=SER=USR304,
// SPACE=(2048,(50,12)),DSN=LARUSN74.A51430
//SAS.UC DDUNIT=SYSDA,DISP=(OLD,DELETE),DSN=&&TEMP1,
// DCB=(RECFM=F,LRECL=624,BLKSIZE=624),SPACE=(2048,(425,106))
//SAS.CL DDUNIT=SYSDA,DISP=(OLD,DELETE),DSN=&&TEMP2,
// DCB=(RECFM=F,LRECL=624, BLKSIZE=624),SPACE=(2048,(425,106))
//SAS.SYSIN DD *
DATA SOIL;
INPUT DATE $ 1-9 PLOT $ 10-19 DEPTH $ 20-29 WWTC 30-39 C 40-49 DWTC 50-59
VOL_AGR 60-69;
IF ABS(WWTC)=0 THEN CON = 'FROZEN';
IF ABS(WWTC ~=0 THEN CON = '    ';
IF DEPTH='0-1' THEN DPTH=1;
IF DEPTH='1-2' THEN DPTH=2;
IF DEPTH='2-3' THEN DPTH=3;
IF DEPTH='3-4' THEN DPTH=4;
IF DEPTH='4-5' THEN DPTH=5;
IF DEPTH='5-6' THEN DPTH=6;
IF DEPTH='6-7' THEN DPTH=7;
IF DEPTH='7-8' THEN DPTH=8;
IF DEPTH='8-9' THEN DPTH=9;
IF DEPTH='9-10' THEN DPTH=10;
IF DEPTH='10-11' THEN DPTH=11;
IF DEPTH='11-12' THEN DPTH=12;
IF DEPTH='12-13' THEN DPTH=13;
IF DEPTH='13-14' THEN DPTH=14;
IF DEPTH='14-15' THEN DPTH=15;
IF DEPTH='15-16' THEN DPTH=16;
IF DEPTH='16-17' THEN DPTH=17;
IF DEPTH='17-18' THEN DPTH=18;
IF DEPTH='18-19' THEN DPTH=19;
IF DEPTH='19-20' THEN DPTH=20;
IF DEPTH='20-21' THEN DPTH=21;
IF DEPTH='21-22' THEN DPTH=22;
IF DEPTH=;22-23' THEN DPTH=23;
IF DEPTH-'23-24' THEN DPTH=24;
IF DEPTH='24-25' THEN DPTH=25;
IF DEPTH='25-26' THEN DPTH=26;
IF DEPTH='26-27' THEN DPTH=27;
IF DEPTH='27-28' THEN DPTH=28;
IF DEPTH='28-29' THEN DPTH=29;
IF DEPTH='29-30' THEN DPTH=30;
IF DEPTH='30-31' THEN DPTH=31;
IF DEPTH='31-32' THEN DPTH=32;
IF DEPTH='32-33' THEN DPTH=33;
IF DEPTH='33-34' THEN DPTH=34;
IF DEPTH='34-35' THEN DPTH=35;
If DATE='19 AUG74 ' THEN DAY=231;
```

```
IF DATE='29 AUG 74' THEN DAY=241;
IF DATE='8 SEPT74 ' THEN DAY=251;
IF DATE='18 SEPT74' THEN DAY=261;
IF DATE='28 SEPT74' THEN DAY=271;
IF CON='FROZEN'THEN GO TO IT;




GM_NOVOL=DWTC-C;
GM_VOL=WWTC-C-GM_NOVOL;
R=GM_NOVOL/(WWTC-C);
FACTOR=50/(2.5*R*1.623);
IT:IF CON='FROZEN' THEN FACTOR=MISS(0);
DROP R;
CARDS;
      -SOILS DATA CARDS-
DATA U1;
INPUT DDNAME=UC UMEAN 1-12 USD 13-24
U1  25-36   U2  37-48   U3  49-60   U4  61-72   U5  73-84
U6  85-96   U7  97-108  U8  109-120 U9  121-132 U10 133-144
U11 145-156 U12 157-168 U13 169-180 U14 181-192 U15 193-204
U16 205-216 U17 217-228 U18 229-240 U19 241-252 U20 253-264 U21 265-276
U22 277-288 U23 289-300 U24 301-312 U25 313-324 U26 325-336 U27 337-348
U28 349-360 U29 361-372 U30 373-384 U31 385-396 U32 397-408 U33 409-420
U34 421-432 U35 433-444 U36 445-456 U37 457-468 U38 469-480 U39 481-492
U40 493-504 U41 505-516 U42 517-528 U43 529-540 U44 541-552 U45 553-564
U46 565-576 U47 577-588 U48 589-600 U49 601-612 U50 613-624;


DATA C1;
INPUT DDNAME=CL CMEAN 1-12 CSD 13-24
C1  25-36   C2  37-48   C3  49-60   C4  61-72   C5  73-84
C6  85-96   C7  97-108  C8  109-120 C9  121-132 C10 133-144
C11 145-156 C12 157-168 C13 169-180 C14 181-192 C15 193-204
C16 205-216 C17 217-228 C18 229-240 C19 241-252 C20 253-264 C21 265-276
C22 277-288 C23 289-300 C24 301-312 C25 313-324 C26 325-336 C27 337-348
C28 349-360 C29 361-372 C30 373-384 C31 385-396 C32 397-408 C33 409-420
C34 421-432 C35 433-444 C36 445-456 C37 457-468 C38 469-480 C39 481-492
C40 493-504 C41 505-516 C42 517-528 C43 529-540 C44 541-552 C45 553-564
C46 565-576 C47 577-588 C48 589-600 C49 601-612 C50 613-624;


DATA A7_;MERGE SOIL U1; DATA ALL74;MERGE A74 C1; PROC PRINT;
TITLE '197_, 2.5 GM SOIL IN H2O AGAR, TOTAL VOL OF 50 ML';
```

```
DATA FROZEN;
SET ALL74;
IF CON='FROZEN';

PROC PRINT;VAR PLOT DEPTH DATE CON;
TITLE '197_ FROZEN SAMPLES';
DATA TRANS7_;
SET ALL7_;
DROP DEPTH DATE UMEAN CSD CMEAN USD WWTC C DWTC FACTOR CON;
IF CON='FROZEN' THEN U1=MISS(0);
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HIGHER FUNGI IN SOILS OF COASTAL ARCTIC TUNDRA PLANT COMMUNITIES

by

Gary A. Laursen

(ABSTRACT)

Presence and abundance of filamentous soil mycelium was determined in North American coastal Arctic tundra soils near Barrow, Alaska. Soils were examined at one centimeter intervals from the surface to the depth of thaw, 0-24 cm, over a three year period during the International Biological Programme Tundra Biome study. Examined were 1217 soil samples, and 57,850 microscopic fields which clearly made this quantitative study of soil fungi the most comprehensive of its kind for tundra. Over 30 study plots were regularly sampled along a 1400 meter moisture dominated gradient. The plots were conveniently categorized into one of five principal habitats in polygonally dominated terrain. The five habitats were polygon troughs, rims, low centered basins, high centered and flattened polygon tops, and mesic tundra meadows. All plots were described vegetatively and physiographically.

Presence of soil fungi was expressed in meters of mycelium per gram dry weight of soil (m/gdws) and grams per square meter to a 1 cm depth. Mycelium averaged 700 m/gdws and 1.05 $g/m^2/cm$ to 7 cm during the 1972-1974 study. Mycelium values ranged from 213 to 3504 m/gdws and .34 to 8.11 $g/m^2/cm$ at the 1-2 cm depth, and from 76 to 445 m/gdws and .29 to 1.97 $g/m^2/cm$ at the 6-7 cm depth.

Seasonal fluctuation of mycelium showed early season vernal highs

followed by an abrupt decline to mid season, a build up to a Fall peak concurrent with fungal fruiting and a general decline to season endings and freeze-up. Amplitudes of mycelium level fluctuation were greater and showed greater variation in surface soils, 1-2 cm, as contrasted to the deeper profile layers, 6-7 cm. Mycelium production rates showed that 1 m of initial mycelium gave rise to 2.7 m by season's end.

Over 75 % of the fungal mycelium was concentrated in the upper 4-5 cm of the soil profile. The 2-4 cm depth was also the zone of maximum vascular plant root concentration. Low levels of resident mycelium were detected at 24 cm depths in all habitats that could be sampled to that depth. Mycelium abundance decreased significantly in highly mineralized soils, but increased at greater depths where burried peat substrates were found.

Clamped hyphae were most abundant, 51 %, in soils of rim habitats and least, 1 %, in low centered basin habitat soils. Polygon rim soils also supported greater numbers of mycorrhizal forming vascular plants.

Soil moisture was found to be the single most important abiotic variable to influence presence and abundance of soil fungi. Optimum soil moisture ranged from 300-450 dry wt. %. Soil moisture also decreased with depth in the soil profile as did the abundance of mycelium. Optimum values for soil bulk density (g/cc) ranged from .2-.3 g/cc. The influence of soil moisture on mycelium abundance was separable from those influences of soil bulk density of same. Mycelium was least abundant where soil bulk densities were greatest, on polygon

top habitats.

Little or no correlation was found to exist between soil temperature and mycelium abundance. Fungi growth was most closely associated with temperatures of 4-5 C in that 69 % of the net fungal growth could be explained. Correlations of mycelium to soil carbon showed no correlation. However, where soil carbon % was greatest mycelial abundance was least. Mycelium abundance was correlated, $r^2 = .85$, most highly with labile phosphorus in basin habitat soils even though polygon troughs had the greatest labile phosphorus levels in soil solution. The multiplicative effect of all variables was far more significant than any single variable.

Hyphal widths averaged 2.75 µm. In situ growth studies showed a mycelium growth rate of 1.5 mm/day. Percent colonization of a nylon mesh substrate was low and ranged from 2-19 %. Growth rates of mycelium were highest in soils of trough habitats and lowest in soils of polygon top habitats. Insignificant amounts of soil carbon, .96-1.30 % of total, were incorporated into the mycelium. Phosphorus composition in mycelium was .9 %, which was a 10^3 phosphorus increase in fungal tissues compared to an equal weight of soil. Nitrogen levels were less significant than phosphorus. If only ammonia nitrogen (NH_3-N) was absorbed by mycelium then $\frac{1}{2}$ to all of the available NH_3-N in the soil was absorbed. Caloric values of fungal tissues ranged from 3800-4900 cal/gdw.