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Questions for F.A. Pokorny:

GARY HUTT: What was the pH in the bark used for your nitrogen fertility study?

FRANK POKORNY: Initially the bark had a pH of 4.1. It was brought up to 6.2.

GARY HUTT: How does pH affect the choice of a nitrogen source?

FRANK POKORNY: If pH is high, the nitrogen material should be acid forming; if low, the fertilizer should give a basic reaction. The pH level, of course, does affect the availability of other nutrients.

RAY SELF: How do you obtain bark with the correct assortment of particle size?

FRANK POKORNY: If the bark is run through a ¾-inch screen, it has a good distribution of fine and coarse particles that is suitable for both propagation and growing.

FACTORS AFFECTING QUALITY OF COMPOSTS FOR UTILIZATION IN CONTAINER MEDIA[1]

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A variety of publications from the United States

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(9,10,16,22,28), Norway (27), Belgium (4,5,6), Finland (18), and Japan (30) have discussed composting of tree barks for use in container media. Although differences in properties of bark from tree species are considerable, established methods for production of high quality composts are remarkably similar. The composting process comprises a complex series of biological events that remove mostly cellulose (wood and cambium) and various toxins (24,29) from bark and leave humic acid, lignins and a variety of microorganisms as major end products. In this article, key factors are discussed that affect the composting rate of tree barks and quality of the end product. Information presented is based on research performed at the Ohio Agricultural Research and Development Center during the past 8 years as well as research at other institutions. Some guidelines were established in cooperation with various commercial operations that produce composts for container media.

Composting process. Composting has been defined as the biological decomposition of organic constituents in wastes under controlled conditions. An important term in this definition is "controlled" which distinguishes composting from natural rotting or putrefaction such as occurs in open dumps, manure heaps, or in field soil (11). Basically the process can be divided into three phases: 1) an initial phase of 1 to 2 days during which easily degradable soluble compounds are decomposed, 2) a thermophilic phase (possibly several months) during which high temperatures occur and in which mostly cellulose is degraded, and 3) stabilization, a period during which the rate of decomposition decreases, temperatures decline, and antagonistic and other ambient temperature microorganisms recolonize the compost. A detailed description of the composting process is given in: "Composting, a study of the process and its principles" (11).

Bark used for container media generally is composted in windrows (3 to 4 m wide, 2 to 2.5 m high). Since the process is aerobic, windrows should not be covered with polyethylene but may be under a roof in areas of high rainfall. The surface on which windrows are placed should provide adequate drainage to avoid anaerobic pockets in the base of windrows.

The oxygen concentration in the gas phase of a windrow should be maintained above 0.1% and preferably between 5 to 12% (8,26). The optimum temperature for composting of hardwood bark is 40° to 55°C (4,6). At high temperatures lower rates of decomposition occur (19). However to reach thermophilic conditions (>40°C) throughout a windrow, temperatures in the center of a windrow usually reach 55° to 70°C (16).

The optimum pH for composting ranges from 6.5 to 8.5

(6,21). The pH of fresh bark ranges from 4.0 to 5.5. Addition of ammonium nitrate does not raise the pH significantly, whereas urea or anhydrous ammonia does (5,16,27). This is the primary cause for higher rates of decomposition observed in bark treated with ammonium N sources (4,5,6).

The optimum moisture content during composting is 50 to 65% on a wet weight basis (6,20). Moisture contents below 40% significantly reduce the rate of decomposition (11). Higher levels may result in accumulation of free water in the bottom of windrows and yield a spoiled silage odor. Frequent turning after free standing water is removed usually corrects this problem due to drying of particles and aerobic decomposition of fermentation products. However, sour compost in which the pH has dropped below 4.0 is no longer usable. Readings as low as pH 1.9 have been encountered (2). These samples were extremely toxic and when used killed all vegetation.

Aeration, moisture content and particle size are interrelated. Coarse bark aerates better and can be stacked in higher windrows than finely ground bark. However, coarse bark dries out readily and water may have to be added to keep the moisture content at optimum levels. Equipment should not be driven onto stacks in the preparation of windrows since it causes compaction and subsequent fermentation (2,16).

The length of time during which high temperature (thermophilic) decomposition occurs can be reduced significantly by careful control of optimum conditions for composting. Aeration with fans (negative pressure) attached to perforated drainage pipe (8,26) reduced the composting period (Beltsville system) for hardwood bark from 6 months to 4 weeks if followed by 1 month of "stabilization". More sophisticated composting machines (mechanized aerated tanks or aerobic digestors) may reduce this period even further (2 weeks, followed by 1 month stabilization) thus reducing the acreage and heavy equipment needed.

During forced aeration, the moisture content must be monitored carefully and may be maintained above 65%. Excessive aeration dries bark rapidly (below 40%) resulting in low rates of decomposition and may cause ammonia loss. Additional water may have to be added (overhead irrigation), depending upon the season. In this system 50% of the N should be applied as ammonium nitrate to avoid ammonia loss as a result of high pH (above 7.4). In practice 30 second aeration bursts each 20 minutes are adequate to maintain optimum levels in windrows. Fans should be on the down-slope end of pipes. A small hole in the pipe just in front of the fan allows drainage water to escape without reducing aeration pressure significantly.

Tree age and species. Generally, trees are classified as hardwoods and softwoods. Barks from hardwoods such as oak, maple, poplar and alder are typically high in cellulose content (readily degradable carbon) and decompose readily (1). However, barks from softwoods, such as lodgepole pine, eastern red cedar and various spruce species also are high in cellulose (1). Bark from these trees require 1 kg N/m^3 for decomposition during 4 to 6 months composting (16,23,27,30). On the other hand, western white pine, hickory and black walnut contain less cellulose in bark (1) but require composting before use. Finally, barks from large tree specimens of cypress, western larch, Douglas-fir, and white, shortleaf, loblolly, slash and longleaf pines contain little cellulose (1). Less nitrogen is required to decompose these barks to a point where excessive nitrogen deficiency does not occur.

Tree age at harvest has a significant effect on the amount of cellulose as compared to lignin in bark, and subsequently, the nitrogen requirement. Young trees contain proportionly more cellulose in the "top" and branch terminals. Bark from these sources, therefore, requires more nitrogen for decomposition (27). Bark from young pine trees, therefore, needs to be composted, whereas that of older trees generally need not be unless it is to be stored in polyethylene bags. Any type of fresh bark, during storage in sealed bags decomposes. Under such conditions fermentation products are produced which are toxic to a variety of plants.

Debarking and grinding. Various types of debarkers are in use. Ring and drum debarkers remove little wood from logs and, generally, produce bark with a wood content of less than 10%. Rosserhead debarkers remove considerable wood in addition to bark. The percentage of wood in this bark will vary depending on the time of year at which bark is harvested (27). Hosmerhead debarkers follow the contour of the log and remove less wood than Rosserhead debarkers and, therefore, are more suitable for harvesting of bark used in container media.

In the 1960's, whole tree chippers were introduced by the paper industry. Entire trees are chipped in the woods and bark is separated from woodchips at the mill by screening. These screenings may contain up to 60% wood and are not suitable for use in container media unless they are composted for long periods, perhaps for several years. In addition to causing nitrogen deficiency on plants, an excessive amount of wood in bark also negates the disease suppressive effect of bark compost. Sawmills that wish to produce bark for container media, therefore, need to deal with sawdust, woodchips and bark separately.

Considerable data has been published on optimum particle size of barks for utilization in container media (3,9). Standards need to be developed. Generally, bark for container media is hammermilled and screened so that all particles pass through a 12.5 mm screen. The ratio of small, medium and large particles determines the percentage pore space at container capacity and the soil moisture characteristic of a medium. No formula is available that may be used to predict such properties. Generally, therefore, large particles should be small enough to avoid handling problems during potting but large enough to assure a high porosity. On the other hand adequate quantities of fines are needed to raise the cation exchange and moisture holding capacities to acceptable levels. Addition of small amounts of sphagnum peat has improved properties of composted hardwood and spruce bark growing media (6,27). Size of bark particles dictates the amount of peat and neutral light weight aggregate (expanded shale, perlite, styrofoam or pumice) that needs to be added to adjust physical properties to optimum levels.

Chemical additives before composting. From a variety of reports (2,4,16,18,23,27) it can be concluded that: a) ammonia is a better source of nitrogen for composting than nitrate, and b) phosphate generally increases the decomposition rate. Optimum amounts of additives for composting are 1 kg N and 0.3 kg P_2O_5 $/m^3$ bark. Higher amounts of N(2-3 kg/m^3) result in excessively high pH readings (5,16,27). Under such conditions free ammonia kills the microflora. Such high amounts of N, therefore, increase the length of time required for decomposition since it will not start again until after the excessive quantities of ammonia have been fixed or dissipated. Part of the added nitrogen may be replaced successfully with poultry manure (30). Addition of all N in the form of poultry manure may decrease the pore space in the bark mixture to undesirable levels resulting in fermentation and problems during utilization.

Stabilized composts may be too high in pH for ericaceous plants. This can be corrected by adding elemental sulfur and iron sulfate (9,16). This, however, should not be added before composting since the pH will be decreased resulting in lower rates of decomposition. Addition of magnesium sulfate (0.5 kg/m^3) to composted hardwood bark (before or after composting) has improved growth of a variety of crops (23).

Quality control. After decomposition, it is usually not possible to visually examine bark compost for wood content and, therefore, determine whether nitrogen deficiency will occur in plants in container media. Chemically, however, the cellulose concentration in refuse composts can be determined with a cuprammonium assay. The procedure, however, is lengthy and has not been applied successfully to hardwood bark compost. Meaningful chemical assays for humic acid content in composts are not yet available.

Mature bark compost should have a "topsoil odor", a pH of 6.4 to 7.2 and a low soluble salts content. The "topsoil" odor is caused by mesophilic actinomycetes that do not recolonize bark until after temperatures decline. Producers of composts for container media, therefore, must use plant bioassays (cucumber or tomato) to test for nitrogen requirements of the compost (16).

Before packaging, composts should be lower than 40% in moisture content or possibly lower, since moisture generated during further decomposition accumulates in plastic bags. To avoid additional decomposition nitrogenous fertilizer should not be added to compost during bagging. Stabilized composts may be packaged and stored for a year or longer. However, partially decomposed bark may self-heat and become sour due to lack of oxygen supply in bags in storage or during transit. Stacks on pallets in storage should be spaced to assure adequate ventilation.

The length of time during which hardwood bark needs to be composted depends on many factors. So far effects of cellulose concentration in bark of the tree species used in addition to the composting method have been discussed. The proportion of bark in a growing medium also has an effect. Increasing proportions of bark in a peat-bark medium required longer and longer periods of composting in windrows to produce 'Bright Golden Anne' chrysanthemum plants equal in quality to the controls (23). With 1:1 mixtures of bark-peat, only 1 month of composting was needed; with 2:1 mixtures, 2 months, 3:1 mixtures, 6 months and with bark alone, 10 months of composting were required to produce total plant growth equal to control plants.

Preparation of container media. Typically, media are prepared after composting, although ingredients may be mixed before. Grinding or excessive mixing after composting breaks particles and exposes cellulose inside large particles and results in additional decomposition and nitrogen deficiency (16). Chemicals utilized in small quantities, therefore, should be premixed with neutral aggregates to decrease the time required for uniform mixing.

Sphagnum peat may be added before composting, but the pH needs to be adjusted to above 5.0 to start the composting process. Aeration of windrows also is more difficult if peat is added before composting, while excessive moisture contents may occur in uncovered windrows that contain peat in areas of high rainfall. This may be avoided by adding pumice, expanded

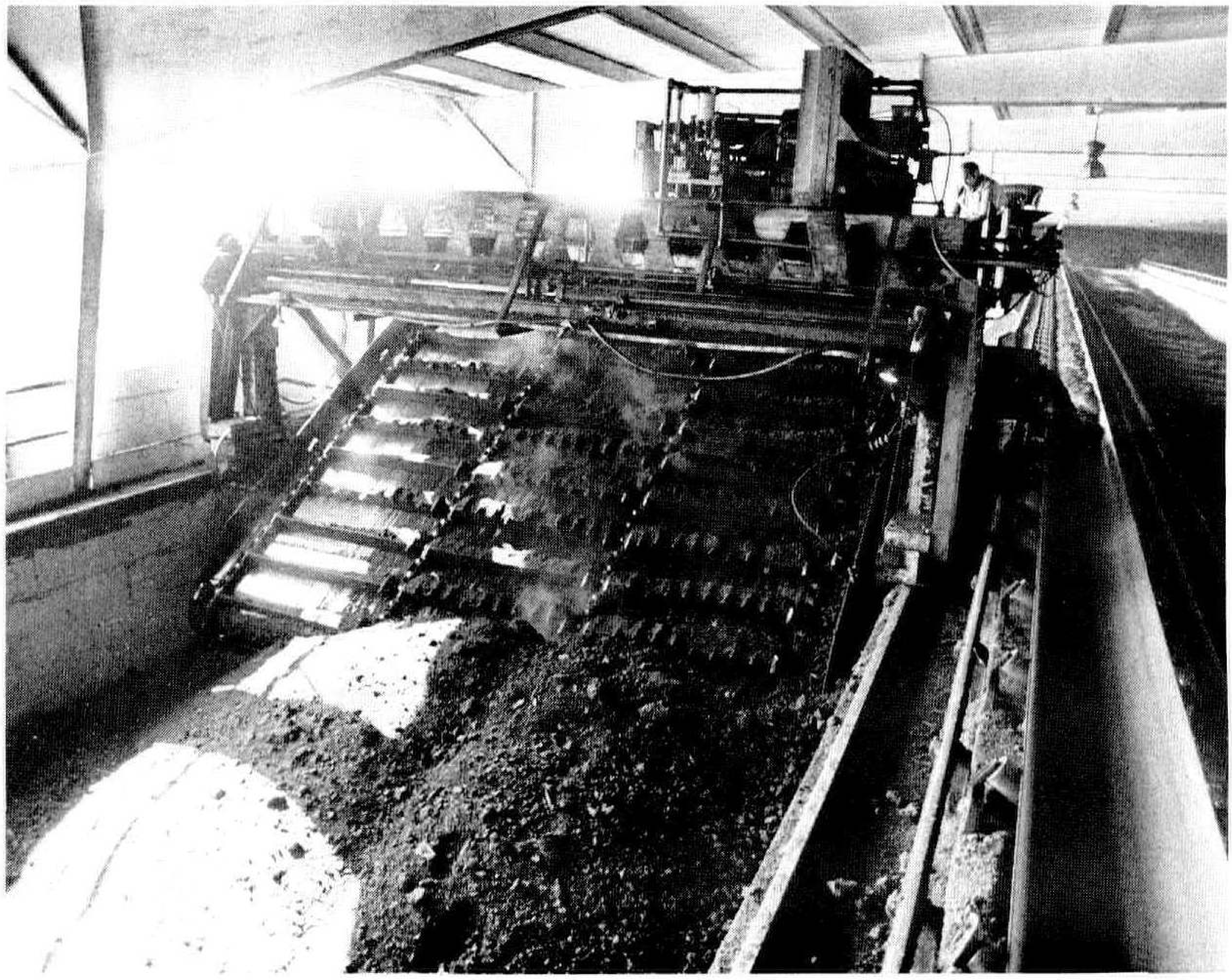

Figure 1. Compost being removed from an aerated bioreactor tank and placed onto conveyor belt. The compost is aerated by fans through perforated floors and turned frequently to expose all organic matter to thermophilic conditions. Tank (4 × 7 × 150 m) on left filled with cow manure and on right with hardwood bark.

shale or other coarse light-weight aggregates. Generally, it is not advisable to add peat before composting. Success of plant growth in container media amended with composts largely depends on the physical properties of the mix and adequate information on these properties is not available.

Disease control. This subject was reviewed in detail in a previous paper (16) and will only be summarized here. Composting involves self-heating at temperatures in excess of 40°C for several weeks and above 70°C for 1 week or more (4,11,16,27). This kills or inactivates plant pathogens, except for some heat-resistant viruses such as tobacco mosaic virus (TMV) and possibly others (13). Composts prepared from vegetable wastes, in particular tomato wastes, therefore, may be contaminated with TMV. In general, composts should not be sterilized since this will kill beneficial microorganisms. Composting on a concrete pad prevents excessive recontamination with plant pathogenic microorganisms.

Hardwood bark compost has fungicidal properties (7) and suppresses all soil-borne plant pathogens that have been examined (13,14,15,25). Composted Douglas fir (17) and pine bark

(12) suppress a wide range of pathogens but pine bark does not suppress *Rhizoctonia solani*. Generalizations, therefore, cannot be made regarding disease suppression by composts. Addition of large amounts of wood to hardwood, Douglas fir, and probably other types of barks destroys the disease suppressive effect against *Phytophthora cinnamomi* and possibly some other pathogens as well (17).

Figure 2. Appearance of roots in a medium consisting of composted hardwood bark, Canadian peat, perlite, 4:3:2 by volume. The medium was not sterilized, and no additional fertilizer was applied.

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PLANNING, RECORDING, AND REPORTING PROPAGATION PROCEDURES AND RESULTS

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In obtaining new information from experimental studies, a set of procedures has been developed by the scientific community which, over the years, has worked very well and is generally adhered to.

For the IPPS, it is advisable for us to follow this same pattern in planning, conducting and reporting experimental projects (1,2). This article has been prepared to assist Society members in setting up experiments, recording results, and preparing their papers for publication in the IPPS Proceedings.

The general outline of these accepted procedures, and how they transform into a manuscript ready for publication are listed below and will be discussed using the final sections of the completed articles as an outline:

1) **Title of article.** Considerable thought should be given in selecting a title which will be brief yet informative and complete. The title of the article is all the reader will see in literature citation lists or reviews so the title should be as informa-